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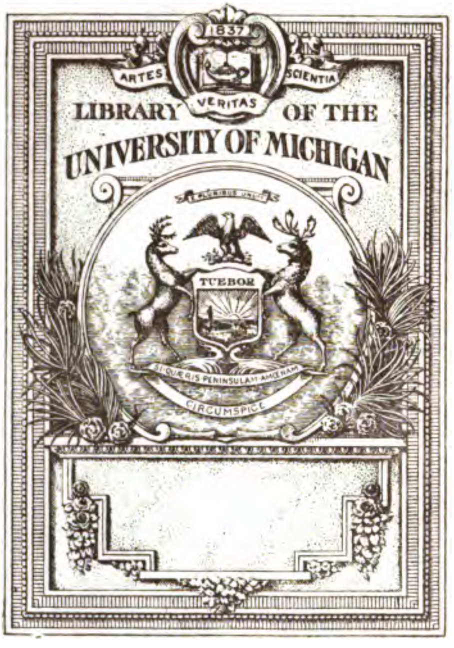
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NAVIGATION

BY

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PREFACE

THIS book is written as an aid for those who wish to study navigation with the intention of taking examinations to obtain officer's licenses. It is assumed that the reader may not have a knowledge of mathematics beyond that of simple arithmetic. No theory or algebraic formulas have been introduced in the body of the book, but only the simple working rules required for the daily routine of the navigator. The author has endeavored to present the subject in a clear and simple manner, yet without omitting anything essential. The methods of computation have been illustrated by numerous examples, and many problems have been left for the student to solve.

No attempt has been made to treat all the subjects in which a candidate will be examined (such as seamanship, rules of the road, etc.), but it was thought advisable to include certain useful information at the end of the book, for convenience of reference.

The value of such a book must depend largely upon the reliability of the statements and the accuracy of the computations. The author will consider it a favor if his attention is called to any errors that may be discovered, so that they may be corrected as opportunity offers.

The author wishes to acknowledge his indebtedness to Professors C. B. Breed and J. W. Howard of the Massachusetts Institute of Technology and to Mr. Rudolph Beaver for valuable suggestions and criticism of the manuscript.

G. L. H.

CAMBRIDGE, *December*, 1917.

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NAVIGATION

CHAPTER I

INSTRUMENTS USED IN NAVIGATION

The Log, Lead, and Sounding Machine

THE subject of navigation is usually divided into two parts, (1) that of obtaining the position of the vessel at any time by keeping account of the directions and distances sailed from some known point, called navigation by dead reckoning; and (2) that of finding the position by observation of celestial bodies, called navigation by observation.

The principal instruments used for navigation by dead reckoning are the log, the compass, and the lead; the pelorus, chart, protractor, parallel rulers, and dividers are also used. The instruments used for navigation by observation are the sextant, the chronometer, pelorus and azimuth sights for the compass, or the shadow pin.

THE LOG

Distances are obtained by measuring the movement of the vessel with reference to the water so as to obtain either the total distance or the speed. This is done either by means of the log or by reading the number of revolutions of the engine. The *chip log*, formerly much used on sailing vessels, consists of a light piece

of board weighted on one edge so as to float in an upright position when thrown into the water (Fig. 1*a*). The line attached to the log is divided into lengths called *knots*, beginning 15 or 20 fathoms from the chip, at a point marked by a piece of red bunting. Each

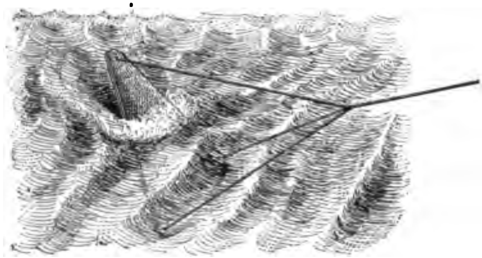


FIG. 1*a*.

of these distances is marked by means of pieces of fish line run through the log line, one for the first, two for the second, etc., each one representing a nautical mile or *knot*. Every two tenths of a knot is marked by a piece of white rag. The log was generally used in connection with a sand glass, and the distances between marks on the log line must be figured such that the length of a knot on the line has the same relation to the sea mile (6080 ft.) that the time of the sand glass has to one hour, or, expressed as a proportion, for a 28^s glass,

$$x : 6080 :: 28 : 3600$$

from which

$$x = 47.29 \text{ ft.}$$
$$= 47 \text{ ft. } 3\tfrac{1}{2} \text{ ins.}$$

Therefore the knots on the log line must be spaced 47 ft. 3½ ins. apart.

When the log is hove the sand glass is started just as the red bunting passes out. When the sand has all run out the observer notes the number of knots and tenths which have passed out. Since the log has not moved through the water this number of knots must be the number of nautical miles (or knots) per hour that the vessel has sailed with reference to the water. If the line is now given a sudden jerk it will free a wooden peg, fastened to two of the lines, so that the chip will lie flat on the water and can be easily hauled aboard.

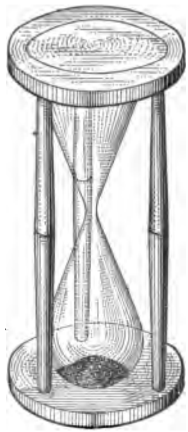


FIG. 1*b*.

The *patent log*, or taffrail log, Fig. 2, is the one generally used at the present time; it consists of a rotator, similar to the propeller of a power boat, attached to a stout line. When this is thrown into the water it is set rotating, the twist being carried by the log line to the wheels of a recording mechanism which is fastened to the rail. The hand of a dial shows the number of miles actually traveled. The dial is read at the beginning and end of each course run and at any other time when the position of the ship is desired. The distances are found by taking the differences between readings of the dial.

If the hand has passed the hundred mark between readings it is necessary to add 100 to the second reading before making the subtraction.

A new log should always be tested by running over some known distance. If it shows an error the correction

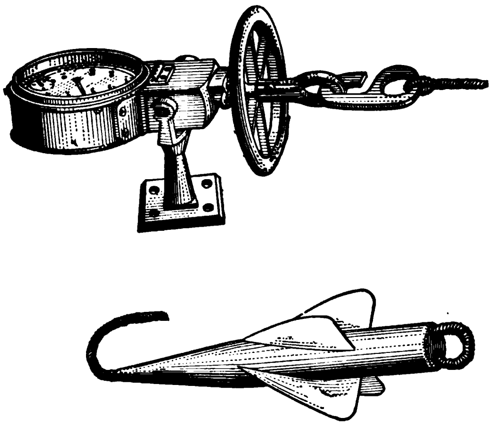


FIG. 2.

per mile should be found and this should be applied to all distances taken with this log.

On steam vessels the distance run may be found very accurately by means of the revolutions of the propeller, after a few runs have been made so that the relation between the number of revolutions and the actual distance becomes known. A careful record of the runs should be kept under varying conditions of weather,

tide, etc., so that the proper speed may be estimated. It is well not to trust entirely to either of these but to take into account both the log and the revolutions in estimating the distance.

THE LEAD LINE

Depths of water (soundings) are measured by means of a lead weight attached to a marked line. The hand lead, weighing about 7 to 14 lbs., is used for measuring depths of about 20 fathoms or less.* The line is marked as follows:

2 fathoms, 2 strips of leather
3 fathoms, 3 strips of leather
5 fathoms, a white rag
7 fathoms, a red rag
10 fathoms, a piece of leather with a hole in it
13 fathoms, same as at 3
15 fathoms, same as at 5
17 fathoms, same as at 7
20 fathoms, with 2 knots
25 fathoms, with 1 knot
30 fathoms, with 3 knots

The marked fathoms are called *marks;* the unmarked fathoms are called *deeps*. Half and quarter fathoms are estimated.

The bottom of the lead is hollowed out so that the depression can be filled with tallow for obtaining samples of the bottom. This is called "arming" the lead.

* The fathom, a length of 6 feet, is the ordinary unit for measuring depths.

THE SOUNDING MACHINE

For deep-sea sounding the best instrument is the "deep-sea sounding machine," the Thompson machine being probably the most widely known. This consists of a heavy lead to which is attached a cylindrical case containing a glass tube arranged so as to measure depths by means of the pressure exerted by the water. The pressure forces water into the tube and the height of the water is indicated by discoloration of a chemical placed in the tube. A scale accompanies the instrument for measuring the fathoms directly. The machine is lowered by means of fine piano wire running off a reel. In using this machine it is not necessary to stop the vessel, or even to slow down, because the machine registers the depth regardless of the length of wire that is out.

Soundings shown on the chart are the depths below "mean low water." They may be in feet or in fathoms, according as they appear on shaded (shoal) areas or on white (deep) areas. When navigating in shoal water it will be necessary to allow for the height of tide to obtain the actual depth at the time.

PROBLEM

What would be the length of the knot on a log line to be used with a 14^s glass?

Ans. 23 ft. 8 ins.

CHAPTER II

THE COMPASS

THE mariner's compass consists of a magnetic needle, or a group of needles, to which is attached a circular card marked with the *points* or the degrees to show the course steered. The magnet and card are suspended on a pivot in a bowl and covered with a glass; the best compasses have the bowl filled with a liquid to steady the needle and to diminish the pressure on the pivot. If not affected by iron or by electric currents the compass needle points to magnetic north and consequently shows the *magnetic* course. This is not usually the same as the *true* course.

The *true* course is the angle the ship's keel makes with the true (geographical) meridian. The *magnetic* course is the angle made by the keel with the magnetic meridian. The *compass* course is the angle made by the keel with the compass needle itself; it will differ from the magnetic course if the compass is affected by iron of the ship or of the cargo. The compass course may also include the errors of leeway and current and the heeling error. The compass course is the one you steer. The true course is the one you get when you observe the sun, or when you take a course from the true meridians of the chart.

Compasses are marked in three different ways. When the "points" of the compass are used the circumference

of the card is first divided into four quadrants by marking the cardinal points, N, E, S, W; then these quadrants are each divided into halves by the intercardinal points NE, SE, SW, NW. These spaces are again subdivided

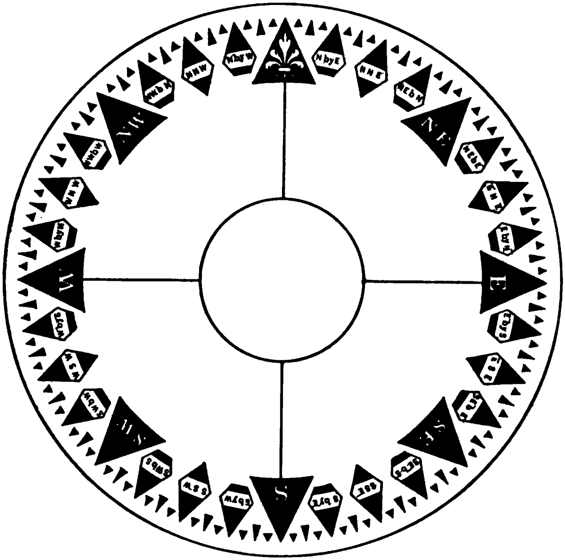


FIG. 3.

by adding the NNE, ENE, ESE, etc., points. Halfway between these points are placed the points marked N by E, NE by N, NE by E, E by N, etc., giving in all 32 points of the compass. In order to show courses more accurately the spaces between the points themselves are

divided into quarters; these are read N $\frac{1}{4}$ E, N $\frac{1}{2}$ E, N $\frac{3}{4}$ E, etc. (Fig. 3). The points and quarter points are given in their order in the following table, together with the angle in degrees which they make with the meridian. The point equals $360° \div 32$, or $11° 15'$. The quarter point equals one fourth of $11° 15'$ ($2° 48' 45''$) or nearly $3°$. This is accurate enough for steering sailing vessels. For steam navigation smaller divisions are desirable.

Notice that when reading the quarter points we always proceed from the N toward the E or W, or from the S toward the E or W, except when counting from a cardinal point or from an intercardinal point, in which case we count back toward the meridian. For example we may say E $\frac{1}{2}$ N, not E by N $\frac{1}{2}$ E; or, NE $\frac{1}{4}$ N, not NE by N $\frac{3}{4}$ E. This is the practice in the United States Navy.

In some localities, however, it is the custom to count from the intercardinal points each way for two points. For example, they would say NE by N $\frac{1}{2}$ N instead of NNE $\frac{1}{2}$ E, as given here.

	Points	Angular measure		Points	Angular measure
North to east		° ′ ″	East to south		° ′ ″
North	0	0 00 00	East	8	90 00 00
N ¼ E	¼	2 48 45	E ¼ S	8¼	92 48 45
N ½ E	½	5 37 30	E ½ S	8½	95 57 30
N ¾ E	¾	8 26 15	E ¾ S	8¾	98 26 15
N by E	1	11 15 00	E by S	9	101 15 00
N by E ¼ E	1¼	14 03 45	ESE ¾ E	9¼	104 03 45
N by E ½ E	1½	16 52 30	ESE ½ E	9½	106 52 30
N by E ¾ E	1¾	19 41 15	ESE ¼ E	9¾	109 41 15
NNE	2	22 30 00	ESE	10	112 30 00
NNE ¼ E	2¼	25 18 45	SE by E ¾ E	10¼	115 18 45
NNE ½ E	2½	28 07 30	SE by E ½ E	10½	118 07 30
NNE ¾ E	2¾	30 56 15	SE by E ¼ E	10¾	120 56 15
NE by N	3	33 45 00	SE by E	11	123 45 00
NE ¾ N	3¼	36 33 45	SE ¾ E	11¼	126 33 45
NE ½ N	3½	39 22 30	SE ½ E	11½	129 22 30
NE ¼ N	3¾	42 11 15	SE ¼ E	11¾	132 11 15
NE	4	45 00 00	SE	12	135 00 00
NE ¼ E	4¼	47 48 45	SE ¼ S	12¼	137 48 45
NE ½ E	4½	50 37 30	SE ½ S	12½	140 37 30
NE ¾ E	4¾	53 26 15	SE ¾ S	12¾	143 26 15
NE by E	5	56 15 00	SE by S	13	146 15 00
NE by E ¼ E	5¼	59 03 45	SSE ¾ E	13¼	149 03 45
NE by E ½ E	5½	61 52 30	SSE ½ E	13½	151 52 30
NE by E ¾ E	5¾	64 41 15	SSE ¼ E	13¾	154 41 15
ENE	6	67 30 00	SSE	14	157 30 00
ENE ¼ E	6¼	70 18 45	S by E ¾ E	14¼	160 18 45
ENE ½ E	6½	73 07 30	S by E ½ E	14½	163 07 30
ENE ¾ E	6¾	75 56 15	S by E ¼ E	14¾	165 56 15
E by N	7	78 45 00	S by E	15	168 45 00
E ¾ N	7¼	81 33 45	S ¾ E	15¼	171 33 45
E ½ N	7½	84 22 30	S ½ E	15½	174 22 30
E ¼ N	7¾	87 11 15	S ¼ E	15¾	177 11 15

	Points	Angular measure		Points	Angular measure
South to west		° ′ ″	West to north		° ′ ″
South	16	180 00 00	West	24	270 00 00
S ¼ W	16¼	182 48 45	W ¼ N	24¼	272 48 45
S ½ W	16½	185 37 30	W ½ N	24½	275 37 30
S ¾ W	16¾	188 26 15	W ¾ N	24¾	278 26 15
S by W	17	191 15 00	W by N	25	281 15 00
S by W ¼ W	17¼	194 03 45	WNW ¾ W	25¼	284 03 45
S by W ½ W	17½	196 52 30	WNW ½ W	25½	286 52 30
S by W ¾ W	17¾	199 41 15	WNW ¼ W	25¾	289 41 15
SSW	18	202 30 00	WNW	26	292 30 00
SSW ¼ W	18¼	205 18 45	NW by W ¾ W	26¼	295 18 45
SSW ½ W	18½	208 07 30	NW by W ½ W	26½	298 07 30
SSW ¾ W	18¾	210 56 15	NW by W ¼ W	26¾	300 56 15
SW by S	19	213 45 00	NW by W	27	303 45 00
SW ¾ S	19¼	216 33 45	NW ¾ W	27¼	306 33 45
SW ½ S	19½	219 22 30	NW ½ W	27½	309 22 30
SW ¼ S	19¾	222 11 15	NW ¼ W	27¾	311 11 15
SW	20	225 00 00	NW	28	315 00 00
SW ¼ W	20¼	227 48 45	NW ¼ N	28¼	317 48 45
SW ½ W	20½	230 37 30	NW ½ N	28½	320 37 30
SW ¾ W	20¾	233 26 15	NW ¾ N	28¾	323 26 15
SW by W	21	236 15 00	NW by N	29	326 15 00
SW by W ¼ W	21¼	239 03 45	NNW ¾ W	29¼	329 03 45
SW by W ½ W	21½	241 52 40	NNW ½ W	29½	331 52 30
SW by W ¾ W	21¾	244 41 15	NNW ¼ W	29¾	334 41 15
WSW	22	247 30 00	NNW	30	337 30 00
WSW ¼ W	22¼	250 18 45	N by W ¾ W	30¼	340 18 45
WSW ½ W	22½	253 07 30	N by W ½ W	30½	343 07 30
WSW ¾ W	22¾	255 56 15	N by W ¼ W	30¾	345 56 15
W by S	23	258 45 00	N by W	31	348 45 00
W ¾ S	23¼	261 33 45	N ¾ W	31¼	351 33 45
W ½ S	23½	264 22 30	N ½ W	31½	354 22 30
W ¼ S	23¾	267 11 15	N ¼ W	31¾	357 11 15
			North	32	360 00 00

In order to divide the circumference a little finer and also to use a division which is more convenient for calculation the card is divided into 360 degrees. These degrees were formerly marked by having each of the four

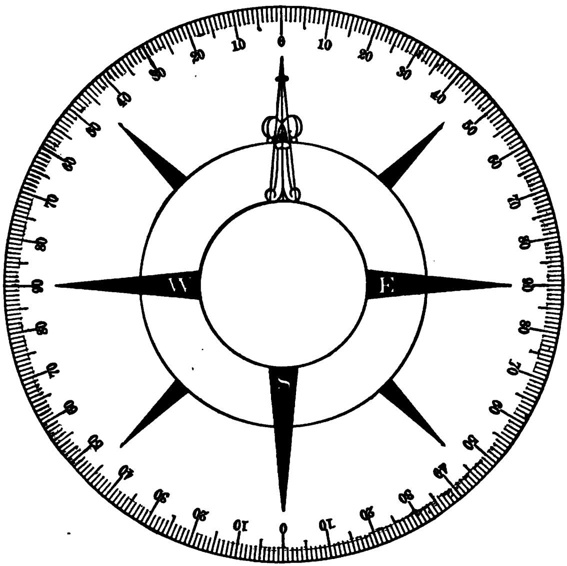


FIG. 4.

quadrants divided into 90 degrees, starting from the N and S points as 0°, the 90° points being at the E and W (Fig. 4). When this system is used a course is shown by writing first the N or S point, whichever is nearer, then

the number of degrees, then the E or W, according to which way the degrees are counted. For example, S 30° E, N 65° W. Courses are not usually reckoned beyond 90° in this system.

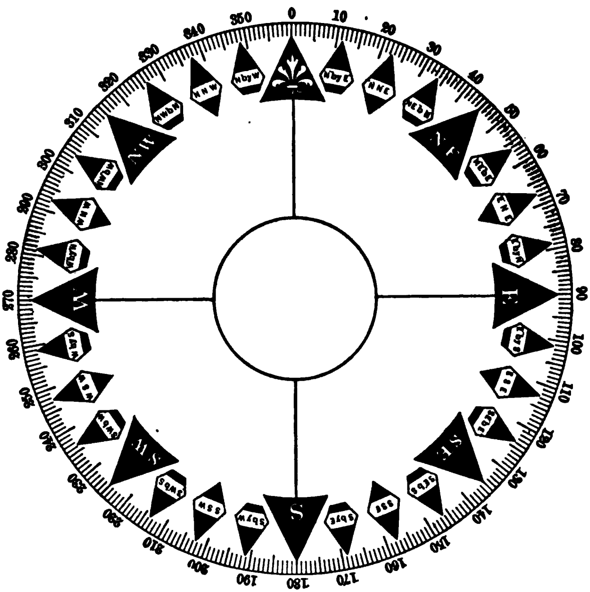


FIG. 5.

A third way of dividing the circumference, which is coming into general use, is to number the degrees starting from 0° at the N point, right-handed (with the sun) up to 360° (Fig. 5). It is not necessary to use any letters

in naming a course in this system. A course of 90° is E, 180° is S, 270° is W, and 360° is N. The navigator should make himself familiar with this system because it has decided advantages over the others. The following comparison will show the relation existing among the three different systems.

Points		Quadrants		Azimuths
NE	=	N 45° E	=	45°
SE	=	S 45° E	=	135°
SW	=	S 45° W	=	225°
NW	=	N 45° W	=	315°

BOXING THE COMPASS

Although the degrees are much used, the points will be found marked on nearly all compasses, and the navigator should be perfectly familiar with them and be able to repeat the names of the 32 points in proper order, either way, around the compass. This is called "boxing the compass."

LUBBER LINE

On the inside of the bowl of the compass is a line set parallel to the keel of the vessel, called the *lubber line*. The point of the compass or the number of the degree which is opposite this line is the compass course on which the ship is then headed.

VARIATION

Variation is the name given to the angle between the magnetic meridian and the true meridian; that is, it is the angle which the N and S line of a correct compass

makes with the true (geographical) meridian, which is a line passing through the earth's poles. In reckoning the variation we start at the true N as 0° and turn through the required number of degrees to the right (East) or to the left (West). The N magnetic pole is not the same as the earth's N pole, but is situated (at present) north of Hudson Bay and at a considerable distance from the true pole. The compass needle tends to point toward the magnetic pole and therefore does not point toward the true N pole except in a few places on the earth's surface. In the middle of the N. Atlantic Ocean the compass needle points about 20° to 25° West of true north. In the middle of the N. Pacific it points about 10° East of true north.

Along a line passing through Brazil, Venezuela, Haiti and South Carolina, it points true north and there is no variation. There is another line of "no variation" passing through Australia, Sumatra, British India, Arabia, and the Black Sea.

The amount of the variation in any part of the world may be taken from the sailing charts, the "Pilot chart," or from the "Variation chart." It is usually indicated by dotted lines drawn for every 5° (sometimes every 1°) of variation. On coast charts the variation is usually shown by means of a *compass rose* printed on the chart and turned through the proper angle to show the variation. It is stated on the chart that the variation is so many degrees E or W in a certain year, and the annual change is also given.

NAMING THE VARIATION

If the N point of the compass is to the **East** of true North the variation is called *East*. If it is **West** of true North the variation is called *West*.

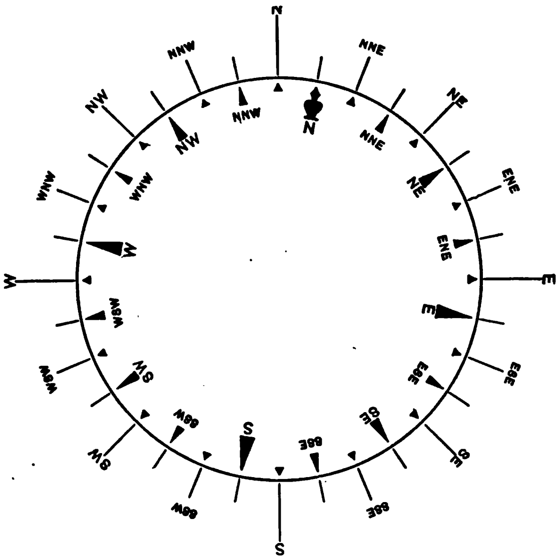


Fig. 6.

CORRECTING A MAGNETIC COURSE FOR VARIATION

If the variation is **East**, as shown in Fig. 6, it will be seen that all **true** courses are to the **right** of the corresponding magnetic courses. For example, if the N end

of the compass is one point to the East (right) the true course E by S is the same direction as the magnetic course East, that is, the true course is found to the right of the magnetic course (on the card) when looking from the center of the compass along the course. This is true of every course so long as the variation is one point East.

Therefore to correct a magnetic course for variation, apply the amount of the variation to the *right* when the variation is *East*, to the left if it is West.

To change a true course into a magnetic course this rule must be reversed, easterly variation being applied to the left.

The above general rule holds true, no matter how the course may be indicated. If the course is shown by the degrees of the quadrant, as N 30° E, N 30° W, the variation will have to be added or subtracted according to which quadrant the course is in. If the magnetic course is either in the NE or the SW quadrants and the variation is E the true course is found by adding the variation. If the magnetic course is either in the NW or the SE quadrants the true course is found by subtracting the E variation. For W variation the opposite is the case. This rule may be remembered by means of the following diagram.

	N	
E, Subtr. W, Add		E, Add W, Subtr.
W		E
E, Add W, Subtr.		E, Subtr. W, Add
	S	

If the compass is divided into degrees and numbered from the N point right-handed to 360° the manner of making the correction is much simpler. In this case when going to the right you *always* add. That is, if the variation is East the true course is found by adding the variation, no matter which quadrant the course is in. If the variation is West the true course is obtained by subtracting the variation from the magnetic course. (If the variation is larger than the course add 360° to the course before subtracting.) This rule is easier to remember and there is less chance of going wrong.

EXAMPLES

1. Magnetic course SE by S, variation ½ pt. E, find true course. Variation is E, so true course is ½ pt. to the right, which is SSE ½ E.

2. Magnetic course, N 30° E, variation 10° W, find true course. Variation is W, so true course is 10° to the left, which is N 20° E.

3. Magnetic course is 280°, variation 25° W, find true course. Variation is W, so true course is to the left (subtract), which gives 255°.

If the student has difficulty with this subject he will find it of assistance to mark out a compass on a circular piece of cardboard and to mark a similar one on a larger piece of cardboard and put a pin through the centers. The small compass may then be turned into any position desired; the small card will show compass courses while the larger card shows true courses.

DEVIATION

If there is iron or steel* near the compass it will be turned out of its true direction and will not read a magnetic course. The amount by which it is turned from the magnetic meridian is called the *deviation*. It is called **East** if the north end of the compass is drawn to the East (right) of magnetic north. In iron vessels the deviation is likely to be large and it is therefore very important to determine its amount. In vessels in which powerful electric currents are used there may be large compass deviations due to this cause. The deviation not only may be a large angle but it may be quite different on different headings of the ship because, as the vessel turns, the mass of iron is placed in different

* Cobalt, nickel, chromium and manganese also are slightly magnetic.

positions with respect to the compass needle and consequently the effect of the attraction is different. The deviation must, therefore, be determined for each different heading of the ship. In some cases the deviation will change even when the ship remains on the same heading, due to heating of the stack, or other causes.

COMPENSATION

In order to keep the deviations as small as possible compasses are usually "adjusted" by placing magnets and soft iron correctors about them in such a way as to counteract the effect of the ship's iron. The amount of the deviation, however, changes with the latitude and with the temperature, as well as with a change in cargo if it contains iron, so the deviation must be frequently determined even though the compass has been perfectly adjusted before leaving port.

ADJUSTING THE COMPASS

There are three parts of the deviation each of which requires a separate correction. The *semicircular* deviation is due to what is called the subpermanent magnetism of the ship combined with the magnetism induced in soft iron by the vertical component of the earth's magnetic force. It is zero at two points and has its greatest value at two intermediate points. It is compensated, while the ship is headed magnetic N or S, by placing magnets athwartships in the binnacle and adjusting their height until the compass indicates magnetic N or S. The ship is then headed E or W and this adjustment completed

by placing fore-and-aft magnets in the binnacle and adjusting their height until the compass reads magnetic E or W. The compass is now correct when the ship is head on the four cardinal points.

The *quadrantal* deviation is due to induction in soft iron by the horizontal component of the earth's magnetic force. It is corrected when the ship is headed on an intercardinal point (NE, SE, etc.) by moving the soft iron correctors (spheres) in or out until the error of the compass heading disappears.

The *heeling* error is only present when the ship is not on an even keel. It may be detected by noting the vibration of the card when the ship is headed N or S and is rolling. It is corrected by raising or lowering the heeling corrector (a vertical rod beneath the compass) until the vibrations are reduced to a small amount.

The adjustment of the compass is usually made by an expert, and should not be attempted by the navigator until he has had special instruction.

The errors remaining after adjustment are usually given in the form of a table of deviations (called *residual deviations*). Such a table must not be relied upon entirely because the deviations will change. A pretty safe rule is to determine the deviation every time the course is changed, or at least once a day.

FINDING THE DEVIATION

A simple way of finding the deviation, when it can be used, is to take a spare compass ashore to a place where it will not be affected by iron and where it can be used

to sight the ship. With this compass the magnetic bearing of the ship's compass may be found at any time. When taking bearings it is often convenient to use the azimuth sights. If there are no sights lay a straight-edge (something not magnetic) on the compass and point it at the object. See that it is directly over the center of the compass and then read the degree or point under the straight-edge. With the ship's compass take a bearing of the shore compass in a similar manner and compare the two bearings to find the deviation. The ship's compass should read exactly the opposite point from the shore compass. This should be tried for every two points or every four points around the compass, by swinging the ship and steadying her on each of these headings while the bearings are being taken. Signals may be used to indicate when the bearing from shore is to be taken. This is known as the method of "reciprocal bearings." In making a table of deviations remember that if the magnetic course is to the right of the compass course the deviation is **East.**

When a compass cannot be taken ashore, it may be possible to place the vessel on a range, fixed by two lighthouses or other objects, the magnetic bearing of which is known. The bearings of some ranges may be found on the charts or in the *Coast Pilot.* A comparison of the compass bearing of this range with the known magnetic bearing will give the deviation.

Suppose that a certain range defined by two lighthouses has a magnetic bearing of N 61° W and the compass bearings of this line are taken on eight points

of the compass, we should then have results like the following:

Heading	Compass bearing	Deviation
N	N 63° W	2° E
NE	N 64° W	3° E
E	N 67° W	6° E
SE	N 62° W	1° E
S	N 59° W	2° W
SW	N 56° W	5° W
W	N 53° W	8° W
NW	N 60° W	1° W

If no range is available it may be possible to sight a distant object, say five miles or more away, and to take bearings of this object on different headings of the ship from approximately the same position, as when at anchor. If the magnetic bearing of the object is not known or cannot be found from the chart the average of all the observed compass bearings may be taken as the magnetic bearing. A comparison of the different bearings with this average will give the deviations on the different headings.

At sea it will not be possible to use the preceding methods, and we must rely upon observations of the sun. By means of either the shadow pin (Fig. 7) or the azimuth sights (Fig. 8) the compass bearing of the sun may be found. By means of the Azimuth tables* the sun's true bearing may be found, as explained later. The difference between the two is the total error of the compass.

* Hydrographic Office Publication No. 71, or Burdwood's Tables.

In order to find the deviation it will be necessary to take the variation from the chart and make allowance for this angle. The error remaining, after allowing for variation, is the deviation.

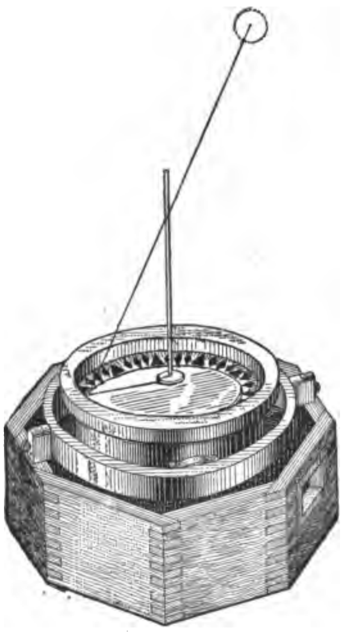


FIG. 7.

The best form of azimuth sight is that having a mirror, which permits taking bearings of the sun at high altitudes. If the compass is not provided with this form of sight the shadow pin must be used when the altitude of the sun is fairly high.

If the shadow pin is used for taking the sun's bearing it should be remembered that the sun's bearing is at the opposite point of the compass from the shadow itself. If the pin is not perfectly straight it may be read in two positions and the mean of the two used as the correct reading. That is, after reading the shadow, turn the pin halfway round

and read again in this second position. For example, if the shadow pin reads 281° in the first position and 280° in the second position the mean reading is 280°½; subtracting 180° we have 100°½ as the sun's bearing by

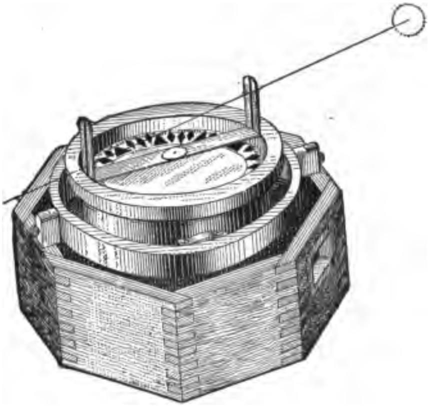


FIG. 8.

compass. If the sun's true bearing by tables is 91° the total error of the compass is 9°½ W, because the true direction is to the left. If the variation is 16° W, the magnetic bearing is 107°, and the deviation is 6°½ E, because the magnetic course is to the right of the compass course.

CORRECTING FOR DEVIATION

To correct a compass course for deviation, in order to find the magnetic course, we proceed in exactly the same

way as when correcting for variation, that is, **if the deviation is East the correct (magnetic) direction is to the right** when looking from the center of the compass along the course in question.

Example. Compass course, S 50° E; deviation, 7° E; find magnetic course. Deviation is E, therefore apply 7° to the right, which gives S 43° E for the compass course. If the variation is 16° W, the true course is found by applying 16° (to the left) to the magnetic course S 43° E, which gives for the true course S 59° E.

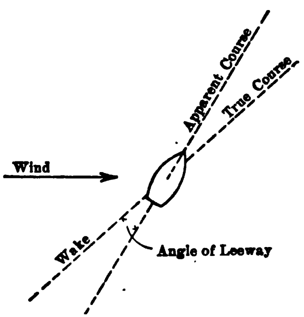


FIG. 9.

HEELING ERROR

When the ship is not on an even keel there is an attraction on the needle called the *heeling error*. This must be determined by noting the difference in the deviation when the vessel is heeled by different angles. The correction may be applied to the magnetic course in the same way as for deviation.

ALLOWANCE FOR WIND, OR LEEWAY

The effect of wind in altering the course of a vessel has nothing to do, in reality, with the error of the compass, but since the allowance for leeway is made in the same manner as the corrections for variation and deviation it

will be explained in connection with those errors. If the wind is on the port side of the vessel (port tack), she will slide off to starboard and the true direction is therefore to the right of the direction indicated by the keel (Fig. 9). The effect of leeway on the port tack (or wind on left) is just the same as the effect of Easterly variation or deviation. The angle of leeway may be estimated by the appearance of the ship's wake, or it may be measured directly by taking the angle between the keel and the log line.

If on the port tack, mark it E; if on the starboard tack, mark it W; and then correct the course just as for variation.

Example. A vessel is sailing SSE (after correcting for variation and deviation), with the wind NE; the leeway is ½ point. What is the true course? The vessel is on the port tack, so the correction is ½ pt. E, therefore apply ½ pt. to the right, which gives S by E ½ E for the true direction.

In correcting for variation, deviation, and leeway, it is convenient to combine all three into one "error of compass" and apply this to the course, as shown below.

Compass course	Variation	Deviation	Leeway	Error	True course
N 35° E	12° W	10° E	5° E	3° E	N 38° E
S 20° E	12° W	8° W	2° W	22° W	S 42° E
241°	12° W	2° E	6° E	4° W	237°

THE PELORUS

Some vessels are equipped with an instrument called a pelorus. This is a compass card (without a magnetic needle) hung in gimbals and fitted with sights for taking azimuths of the sun, or bearings of objects. The card can be turned through any angle on the pivot at the center. It is used chiefly for determining magnetic headings from observations on the sun.

PROBLEMS

1. Correct the following magnetic courses for variation: N 65° E, var. 18° E; S 69° E, var. 18° E; S 40° E, var. 17° E; S 10° W, var. 17° E.

Ans. N 83° E, S 51° E, S 23° E, S 27° W.

2. Correct the following compass courses for variation and deviation: 170°, var. 11° W, dev. 5° E; 210°, var. 10° W, dev. 3° W; 250°, var. 9° W, dev. 1° W; 271°, var. 9° W, dev. 3° E.

Ans. 164°, 197°, 240°, 265°.

3. Correct the following magnetic courses for variation: N 30° E, var. 5° E; N 54° E, var. 4° E; East, var. 4° E; S 80° E, var. 4° E; S 49° E, var. 3° E.

4. Correct the following magnetic courses for variation: NNE, var. 1 pt. E; NE by N, var. 11° ¼ W; S 45° E, var. 14° E; S 10° W, var. 2° W; N 80° W, var. 5° E; 110°, var. 4° E; 260°, var. 20° W; NW by W, var. 6° W.

5. Correct the following courses:

Compass course	Variation	Deviation	Leeway	Tack
NE by E.......	1 pt. E	½ pt. W	¼ pt.	Port
E by S.........	1 pt. E	1 pt. E	¼ pt.	Starboard
SW by S........	1 pt. E	½ pt. E	½ pt.	Starboard
NNW..........	1 pt. E	½ pt. W	¼ pt.	Port

6. Correct the following magnetic courses: SSW, var. 10° W; SW, var. 10° W; WSW, var. 10° W; West, var. 11° W.

Ans. S 12°½ W, S 35° W, S 57°½ W, S 79° W.

7. Correct the following courses:

Compass	Variation	Deviation	Wind
40°	10° W	5° E	5° (port)
100°	9° W	1° W	3° (starboard)
190°	9° W	4° E	8° (starboard)
300°	10° W	3° W	3° (port)

Ans. 40°, 87°, 177°, 290°.

8. Shadow pin reading 317°½; azimuth of sun from tables N 117° E; variation from chart, 18° W; heading, 356°½. Find the deviation.

Ans. 2½° W.

CHAPTER III

CHARTS

CHARTS of the oceans, or sailing charts, show the outline of the coast, the positions of the principal ports, and the depths of the ocean. The variation of the compass is shown by dotted lines drawn for every 5°, or for every one degree, of variation. The annual change of the variation is also given. The compasses shown on these charts give true courses, and on the newer charts they are numbered from 0° right-handed (with the hands of a watch) to 360°. The meridians (longitude) and parallels (latitude) are usually drawn for every 10° or every 20°. The single degrees and fractions are shown on the scales on the margin of the chart.

Charts of the coast are drawn to a larger scale and show elevations of the land, depths of water both in shoal and in deep water, the directions of currents, positions of rocks and shoals, the character of the bottom, positions of lighthouses, buoys, and beacons. The sectors over which the lights are visible are usually indicated. The color and kind of buoys are shown. Buoys marking a channel are red with even numbers on the starboard side of the channel, when approaching from the sea, and black with odd numbers on the port side of the channel. Buoys in mid-channel with vertical black and white stripes must be passed close to.

Buoys with red and black horizontal stripes show obstructions with channels on both sides. Soundings on shaded areas are in feet; those on white areas are in fathoms. These are the depths below "mean low water." The compasses* are usually drawn so as to give **magnetic** bearings. In narrow, difficult channels, ranges are sometimes marked, which are to be followed by the navigator. All abbreviations used on these charts are explained somewhere on the chart itself.

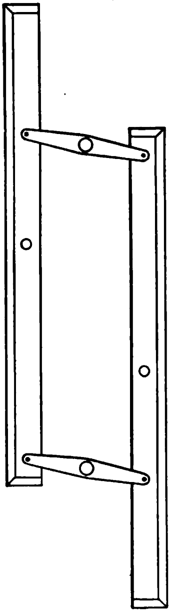


FIG. 10.

The instruments used in connection with chart work are the dividers, the parallel rulers, and the course protractor. The dividers consist of two metal legs, hinged at one end and terminating in fine points. The points may be set at any desired distance apart and used to transfer distances from one part of a chart to another. The parallel rulers, Fig. 10, consist of two rulers joined by two metal strips and so arranged that they are always parallel. By holding one ruler firmly in position and moving the other the ruler may be "walked" across the chart, and any direction on the chart may be transferred

* The compass printed on the chart is called a compass "rose."

from one position to another. The course protractor is a circle, on celluloid or other transparent material, with the degrees (or points) of the compass marked on it, and having a string or an arm pivoted at the center. If the protractor is placed so that the 0° line lies along a meridian and the string or the arm lies along the ship's track, the course may be read off directly from the circle.

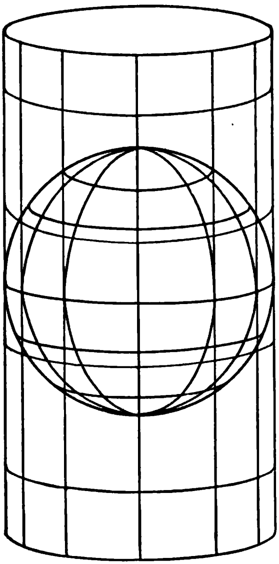


FIG. 11.

The kinds of charts chiefly used by the navigator are the Mercator chart, the Great-Circle chart, and the Polyconic chart.

MERCATOR CHART

The Mercator chart is constructed on the surface of a cylinder supposed to be wrapped around the earth and touching it only at the equator, as shown in Fig. 11. When the map is unwrapped and laid flat the meridians (of longitude) and the parallels of latitude are all straight and at right angles to each other. The degrees of longitude on this chart are the same length all the way around

the equator and in all latitudes. The lengths of the degrees of latitude, however, increase greatly as we go toward the poles. Neither of these conditions is true of the earth itself. The land and water surfaces on the Mercator chart are greatly exaggerated near the pole, and distances cannot be scaled in different parts of the chart by using the same scale. This chart has, however, one very important and useful property. The relation between the length of the degrees of latitude and longitude is the same at any point on the chart as it is at the corresponding point on the earth's surface; consequently, if a straight line is drawn between two ports the angle that it makes with the meridians is the (true) course on which a vessel must sail **continuously** to go from one port to the other. This track is a curve on the earth's surface (Fig. 12), and is called a *rhumb-line*. It is not the shortest possible track, but is the one generally sailed except on long voyages. The distances between points on the chart may be found by using as a scale the length of the nautical mile (minute) at the **middle** latitude, that is, halfway between the latitudes of the two points. (See chart, p. 36.)

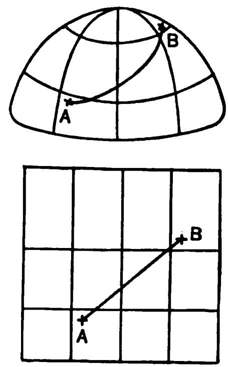


FIG. 12.

GREAT-CIRCLE CHART

A great-circle chart is made by drawing the meridians and parallels on a plane which touches the earth at one point, say latitude 30° N, longitude 30° W, in the middle of the Atlantic Ocean. The meridians are straight, converging lines; the parallels of latitude are all curved, except the equator. This chart is not drawn to uniform scale, and distances cannot be scaled off as on an ordinary land map. But it has one property of great importance to the navigator; every straight line on this chart represents a great-circle track on the earth's surface, that is, the shortest track a ship can sail between two points. To lay out a great-circle track on this chart draw a straight line between the points of departure and destination (Fig. 13). It is not convenient to take off the courses from the great-circle chart itself because the meridians are not parallel to each other, but if the latitudes and longitudes of several intermediate points on the track are read off and transferred to the

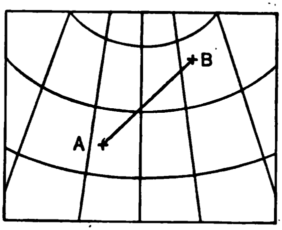


FIG. 13.

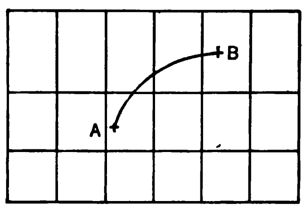


FIG. 14.

Mercator chart (Fig. 14), the courses of the different portions of the track may then be found in the usual way. There are also other ways of finding these courses as well as the distance to sail, some of which will be discussed later. On the chart itself will be found complete instructions for obtaining the courses and distances.

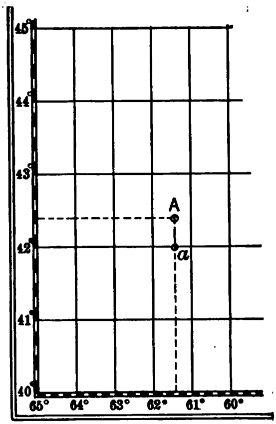


FIG. 15.

THE POLYCONIC CHART

The polyconic chart is seldom used by the navigator in the routine work of navigation, excepting the harbor and coast charts. It is the one best adapted to surveying and mapping; its chief advantage lies in the fact that the same scale applies quite accurately to all parts of the map. The meridians and parallels are both curved, so that courses cannot be taken off conveniently. It is sometimes used in laying down position circles by Sumner's method (see p. 36).

USE OF THE MERCATOR CHART

To find the latitude and longitude of a point A (Fig. 15), on the Mercator chart; Set one point of the dividers on point A and the other on the parallel of latitude at a;

then move the dividers over to the left (or right) margin of the chart, set one point of the dividers on the parallel of *a* and read off the latitude of *A* on the marginal scale at the other point of the dividers.

The longitude is found in a similar manner except that it is read from the scale at the top or bottom of the chart. This may also be done with the parallel rulers. Place the ruler along the parallel of latitude through *a* and move it (parallel) until it passes through *A*. The ruler then passes through the latitude of *A* on the marginal scale at the side of the chart. The longitude is found in a similar way, laying the ruler along a meridian and reading the longitude from the top or bottom of the chart.

To mark the position of the ship when the latitude and longitude are known: Place the parallel ruler on a parallel of latitude, move it until it passes through the latitude of the ship as shown by the marginal scale; then draw a light line. In the same way draw another line, parallel to the meridian, corresponding to the longitude of the ship. The intersection of the two lines is her position. If it is desired to locate the position without drawing any lines, the parallel ruler may be held in the first position while the longitude is found by means of the dividers. If the dividers are held against the ruler with one point on the meridian the other point of the dividers will then be on the required position.

To take off a magnetic course: Lay the parallel ruler on the points between which the vessel is to sail; move the ruler over (parallel) to the nearest compass rose shown

on the chart. See that the edge of the ruler passes exactly through the center of the compass rose. If the compass rose is magnetic the magnetic bearing is read off directly; this is the course on which to steer provided there is no deviation. If the compass rose is on the true meridian the course read will be a true course and must be changed to a magnetic course by allowing for the variation. To find the compass course (on which to steer) allow for the deviation also.

To take a distance from the chart: On coast charts having a scale of nautical miles, take off the distance with the dividers and lay it against the scale of miles, and read off the distance. If the distance is longer than the scale of miles, take a space of say 5 miles or 10 miles in the dividers and step off the spaces along the course; the number of steps times the number of miles in one step is the distance. If there is a small fraction left over take this distance in the dividers and lay it against the scale and read off the distance. If the chart has no scale of miles, as in case of ocean sailing charts, take the miles (minutes of latitude) from the side margin exactly opposite the middle of the track. (See chart, p. 36.)

EXERCISES IN USING THE CHART

1. Select two points on the chart and take off their latitudes and longitudes.

2. By the parallel ruler and compass find the course and distance between these two points.

3. Assume a latitude and longitude for the ship and lay down this position on the chart.

CHAPTER IV

PILOTING

FIXING THE SHIP'S POSITION

To find the position of the ship by cross-bearings: Take simultaneous bearings of two prominent objects (*L* and *H*, Fig. 16), using the azimuth sights or some substitute. Correct these bearings for deviation, and if the chart to

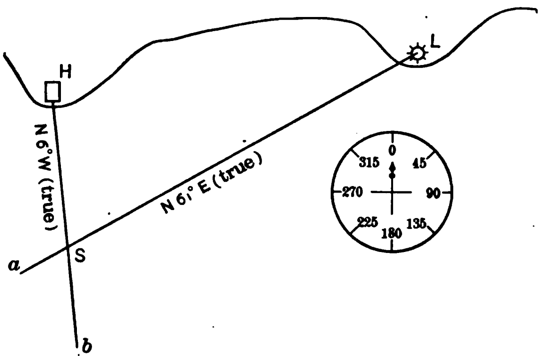


Fig. 16.

be used does not show a magnetic compass, but only a true compass, correct the bearings also for variation. With the parallel rulers transfer the bearing of one of the points, *L*, from the compass rose on the chart to the

object sighted, and draw a line *La*. Then transfer the bearing of the second object, *H*, and draw a second line, *Hb*. The position of the ship at the time the bearings were taken is at the point *S* where the two lines cross each other. In order to define the position of the ship accurately the objects should be selected if possible so

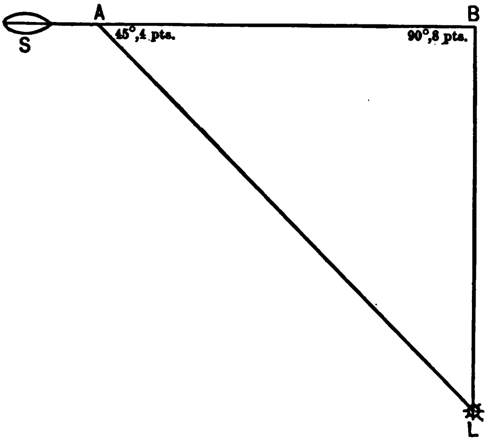


Fig. 17.

that their bearings differ by about 8 points, or 90°. There will always be some error in taking these bearings and this error will have a much greater effect if the angle between the objects is small.

To locate the ship by a four-point bearing: When the ship, at *S* (Fig. 17), is approaching an object, *L*, the angle on the bow is observed, and when it has increased

to four points, as it will be when the ship is at A, the log is read. When the ship is at B, where the object L is abeam (8 pts. off the bow) the log is read again. The distance AB is the difference between the two readings of the log (distance run), and is just equal to BL, the distance of the ship from the object when the latter is abeam. This method of locating the ship is often used for "taking the departure" when starting on a voyage. This is also called *bow and beam bearing.*

To locate the ship by a two-point bearing: Note the log when the object is two points forward of the beam and again note the log when the object is abeam. The ship's distance from the object when abeam is 2½ times the distance run as shown by the log. The same result would be found by taking the log when the object is abeam and again when it is two points abaft the beam.

Some navigators note the log when the object is 1½ pts. forward of the beam and again when it is 1½ pts. abaft the beam. The distance from the object when abeam is twice the distance run.

To locate the ship by a one-point bearing: Read the log when the object is 1 point forward or abaft the beam and also when it is abeam. The distance to the object abeam is in this case 5 times the distance run.

Doubling the angle on the bow: In the four-point bearing (Fig. 17), notice that the bearing when abeam (8 points) is twice the first bearing (4 points). The distance of the ship from the object at the time of the second bearing may always be found by doubling the angle on the bow, no matter what the size of the angle may be.

For example, if the ship is at A (Fig. 18), the angle on the bow is 30°, and when she is at B it is 60°; then the distance from B to L is the same as the distance run, AB. Any other angles would do instead provided the second angle is twice the first. It is better not to use very small angles.

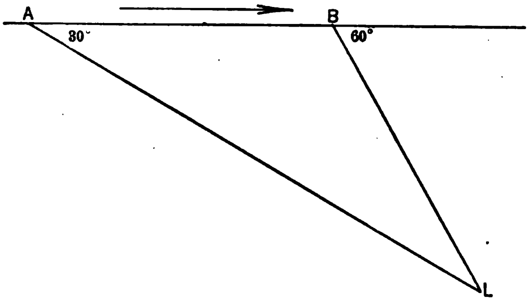


FIG. 18.

Finding the distance of the ship by the vertical (sextant) angle of an object of known height: Suppose the object to be a lighthouse whose height above the water is known to be 70 ft. With a sextant measure the vertical angle between the top and bottom, say 0° 35′. Look in Table 33, Bowditch, for the height and the angle. The corresponding number in the table will be the distance from the object to the ship in nautical miles (in this case, 1.2 mi.).

If the bearing of the lighthouse is also taken the ship's position may be found on the chart, since both her bearing and her distance from a known point have been found.

MAKING A LIGHT

When approaching the land the navigator should look up his list of lights and ascertain their visibility. The distance at which a light is visible is given on charts for an average height above the water line. If the light is observed from a greater height it can be seen at a greater distance and allowance should be made for this fact. If a compass bearing of the light is taken and corrected for deviation, the navigator knows his distance and direction from the light and can mark his position approximately on the chart.

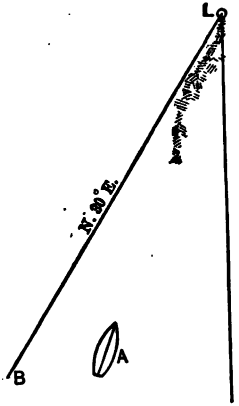


FIG. 19.

THE DANGER BEARING

Suppose the ship to be at *A* (Fig. 19), and that between a visible object *L* and the ship are sunken rocks. Draw a line *LB* which just clears all dangers, as shown on the chart. With the parallel rulers transfer this line to the compass rose and find the bearing. Make allowance for deviation. Suppose the compass bearing to be N 30° E. Then whenever the bearing of the object is less than N 30° E the ship is in danger. When the bearing is greater than N 30° E she will pass clear.

THE (HORIZONTAL) DANGER ANGLE

Suppose that there are sunken rocks or other hidden danger at *A* (Fig. 20) and at *L* and *B* are two visible objects shown on the chart. Draw a small circle around the hidden danger at *A* so that anywhere outside this

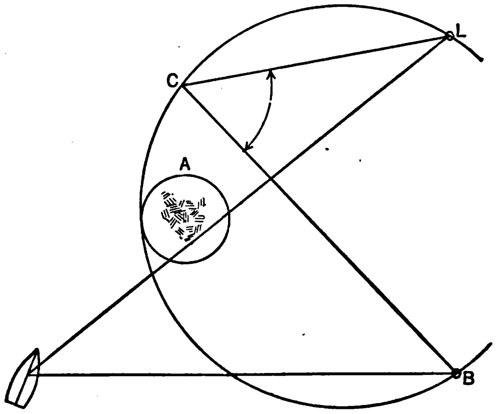


FIG. 20.

circle the danger will be avoided. With the drawing compasses (or dividers) draw a circle through *L* and *B* and touching the outside of the small circle. With a protractor (or with the parallel rulers and the compass rose) measure the angle at some point *C* (on the larger circle) between *L* and *B*. This is the *danger angle*. Measure with the sextant the angle between the objects *L* and *B*. If this angle is less than the danger angle the

ship is outside the large circle and is safe. If the sextant angle is equal to or greater than the danger angle the ship is exposed to danger.

If it is desired to run on the other side of the little circle, draw the large circle so as to touch the small circle on the other side and keep the ship in such position that the sextant angle is greater than the new danger angle.

HOW TO LOCATE BY SOUNDINGS

Heave the lead at regular intervals, and keep account of the time, the log, the course, and the depths. Draw a line, representing the course, on transparent paper. Measure off distances, according to the scale of the chart, representing the different positions of the ship when soundings are taken. Write on the paper in the proper places the depths and the character of the bottom. Place the paper on the chart, turn the line so that it is in the proper direction for the course steered, then move the paper along on the chart parallel to itself until a place is found where the depths correspond with the depths given on the chart. The position of the ship on the chart at any time is then found from the position on the paper. There will seldom be found more than one place on the chart where these depths will correspond.

PRACTICE PROBLEMS

1. Assume two bearings of objects shown on a chart and plot the position of the vessel from these two bearings.

2. What is the distance of the vessel from Minots Ledge Light (Prob. 15, p. 57) when passing it abeam?

Ans. 2.1 mi.

3. The angle between the top of a lighthouse and the water line is measured with a sextant and found to be $0° 23'$. The lighthouse is 120 ft. high. What is its distance? *Ans.* 3.0 miles.

CHAPTER V

DEAD RECKONING — MERCATOR AND GREAT-CIRCLE SAILING

THE position of the ship by dead reckoning is found by keeping account of the courses and distances sailed from a known position and calculating the amount by which the ship has changed her latitude and longitude.

If a ship sails due north or south the number of minutes change in latitude is the same as the number of nautical miles run because one minute of latitude (or in fact 1 minute on any great circle on the earth's surface) equals one nautical mile, or knot, 6080 feet. If a ship in latitude 42° N runs 65 miles south, she will change her latitude 65′ or 1° 05′ and then will be in latitude 40° 55′ N.

In sailing east or west the number of minutes change of longitude does **not** equal the number of miles run, except when on the equator, because the meridians all pass through the poles and therefore the distance between them grows less and less as we go nearer to the pole. The number of minutes of longitude depends upon the latitude as well as upon the number of miles run east or west. In Lat. 60° one mile equals 2 min. of longitude.

PLANE SAILING

If a ship sails at some angle with the meridian, say 56°, then the distance sailed N or S and the distance sailed

E or W may be found by calculating the sides of a right triangle. In Fig. 21 the course is S 56° W and the distance is 10 miles. This is nearly the same as the course SW by W, 10 miles. The distance sailed S, or

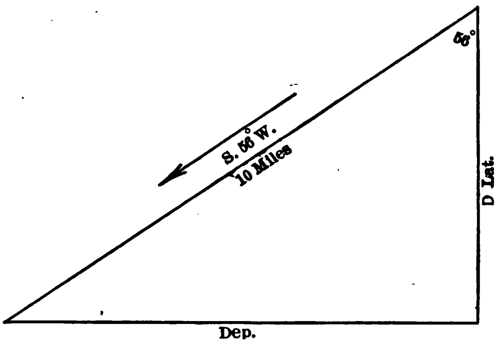


FIG. 21.

southing, is called the *difference in latitude* (D. Lat.) and is found by multiplying the distance run by the cosine of the number of degrees in the course. The distance sailed W, or westing, is called the *departure* (Dep.) and is found by multiplying the distance by the sine of the number of degrees in the course. It is not necessary, however, to actually make these multiplications because the traverse tables (Tables 1 and 2, Bowditch *) contain these numbers for every degree, or for every quarter

* Bowditch, American Practical Navigator (Edition of 1916 or 1917), published by the Bureau of Navigation.

point, and for distances from 1 up to 300 or up to 600 miles. When the course is given in points use Table 1; when the course is in degrees use Table 2.

Entering the table at the page marked with the degrees or points of the course, and looking opposite the distance in miles, we find the Lat. and the Dep. It should be carefully noticed that when the degrees (or points) of the course are found at the top of the page the names "Lat." and "Dep." are to be found at the top; when the course is at the bottom use the names "Lat." and "Dep." at the bottom.

The reason for this arrangement is that the Lat. for 10°, for example, is the same number as the Dep. for 80°, or Lat. at the top is Dep. at the bottom, and the table is arranged so as to avoid printing these numbers twice. Notice that the hundreds in the distance column are not repeated except for every 10 miles.

Example 1. Course S by E, Dist. 10 miles. Required the D. Lat. and the Dep. Look in Table 1 and find course S by E, a one-point course. Opposite Dist. 10 mi. we find Lat. = 9.8 mi. and Dep. = 2.0 mi.

Example 2. Course SW by W, Dist. 10 mi. This course is over 4 points and is therefore at the bottom of a page; opposite 10 miles we find Lat. = 5.6 and Dep. = 8.3.

Example 3. Course S 56° W, Dist. 10 mi. Look in Table 2 for the page marked 56°; this is more than 45° and the degrees will therefore be at the bottom of the page. Opposite the distance 10 miles we find Lat. = 5.6 and Dep. = 8.3.

Example 4. Course 5°, Dist. 50 mi. On the page marked 5° at the top and opposite Dist. 50 we find Lat. = 49.8 and Dep. = 4.4.

Example 5. Course 200°, Dist. 800 mi. This course is 20° more than 180°, so we find it at the top of a page. The Dist. is greater than any Dist. in the table, so take out Lat. and Dep. for 400 mi. (half the Dist.) and double the numbers. The numbers in the table are Lat. = 375.9, Dep. = 136.8. Multiplying by 2, the required numbers are Lat. = 751.8, Dep. = 273.6.

Notice that when the course is greater than four points, or 45°, the Dep. is greater than the Lat.

PARALLEL SAILING

To change the number of miles E or W (departure) into minutes of longitude we multiply the Dep. by the secant of the latitude. Here again it is not necessary to actually make the multiplication because the relation between Dep. and difference of longitude (D. Lo.) is the same as the relation between the Lat. and Dist. in the traverse table.

Therefore to find the D. Lo. enter the traverse table (Table 2) with the degrees of the latitude at the top or bottom of the page and find the Dep. in a column marked "Lat." The distance opposite this Dep. is the number of minutes in the D. Lo. If the degrees are at the top of the page, use names Lat. and Dep. at the top; if the degrees are at the foot of the page use the names Lat. and Dep. at the foot of the page.

Example. A vessel in latitude 50° N, longitude 30° W, sails 60 miles due west. In what longitude is she? On the page (Table 2) marked 50° at the bottom we find in a Lat. column 59.8 (the nearest number to 60). Opposite to this in the distance column is 93 (or 1° 33′), which is the D. Lo. To find the D. Lo. more exactly we notice that 60 is two sixths the way from the number opposite 93 to the number opposite 94, so that 93⅓, or 1° 33′.3 W, is the D. Lo. corresponding to 60 miles Dep. Adding this D. Lo. to the Long. 30° W, we find that the ship is in Long. 31° 33′.3 W. This is known as *parallel sailing.*

MIDDLE LATITUDE SAILING

If, however, the course is not exactly E or W the vessel will change her latitude. In this case it would not be correct to use the Lat. from which the vessel started nor the Lat. arrived at, because the number of minutes of D. Lo. is different in different latitudes. So we use the *middle latitude* when taking out the D. Lo. from the traverse tables. This will be accurate for all ordinary distances such as can be run in a day.

Example. If a vessel sails S 30° W, 200 miles, starting in Lat. 45° N, Long. 60° W, we find for the D. Lat. 173.2 and for the Dep. 100. We first find the new Lat. (called *Lat. in*) as follows:

Lat. left	45° 00′	N
D. Lat.	2 53 .2	S
Lat. in	42° 06′.8	N

That is, if the Lat. left and the D. Lat. are of the same name, add; if of different names, subtract, as in this

example. To look up the D. Lo. we need the **middle Lat.** which is found as follows:

Lat. left	45° 00′ N
Lat. in	42 06 .8 N
Sum	2)87° 06′.8
½ sum = Mid. Lat.	43° 33′.4 N

With this middle Lat. as a course and with Dep. 100 as a Lat. we find in Table 2 as Dist. 139 (= 2° 19′) which is the D. Lo. The *Long. in* is then found as follows:

Long. left	60° 00′ W
D. Lo.	2 19 W
Long. in	62° 19′ W

If the Long. left and the D. Lo. are of the same name, add; if of different names, subtract. This is known as *middle latitude sailing*.

TRAVERSE SAILING

If a vessel sails several courses, as when tacking, this zig-zag track is called a *traverse*. Traverse sailing consists in finding the distance made good to the N or S and the distance made good to the E or W, and reducing the whole traverse to a single course and distance which would carry the vessel from the first point to the last point (Fig. 22). To find the change in her latitude and longitude take out from the traverse tables the Lat. and Dep. for each (true) course, writing each number in its proper column in a table ruled as in the following example. If the course is NE, for instance, put the Lat. in the N column and the Dep. in the E column. Take the sums

of each of the four columns. Take the difference between the N and S columns and also the difference between the E and W columns. Mark the difference in each case with the letter (or name) of the greater. The

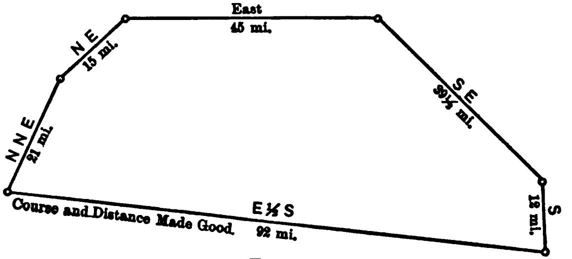


FIG. 22.

difference between the N and S columns is the difference in latitude and may be applied at once to the Lat. left to find the Lat. in. If the D. Lat. is of the same name as the Lat. left it should be added; if of different name it should be subtracted.

Before the new longitude can be found the difference in the departure columns must be changed into D. Lo., using the middle lat. for this purpose, by the rule given on p. 49. The D. Lo. is then added to or subtracted from the Long. left according to whether they are of the same or of different names. To find the course and distance made good (that is, the course and distance equivalent to the entire traverse) look in the traverse table for a Lat. and a Dep. which are abreast of each other on the same page and equal to the Lat. and Dep. made good. It will not usually be possible to find

these exactly, so take the Lat. and Dep. that come the nearest. The course at the top or bottom of the page and the Dist. abreast the Lat. and Dep. are the course and distance required.

Since there are four different courses at the top and bottom of each page it will be necessary to determine from the names of the D. Lat. and the Dep. in which of the four quadrants the course lies. For example, if the D. Lat. is N and the Dep. is E, the course will be between 0° and 90°; if the D. Lat. is S and the Dep. is E, the course is between 90° and 180, etc.

Example. A ship in Lat. 51° 10′ N, Long. 40° 19′ W, sails NNE, 21 mi., NE, 15 mi., E, 45 mi., SE, 39.5 mi., S, 12 mi. What is her position by dead reckoning and what are the course and distance made good?

True Course	Dist. (miles)	D. Lat. N	D. Lat. S	Dep. E	Dep. W	D. Lo.
NNE.......	21	19.4		8.0		
NE.........	15	10.6		10.6		
E...........	45			45.0		
SE.........	39.5		28.0	28.0		
S...........	12		12.0			
		30.0	40.0	91.6		145½′ =
			30.0			2° 25′.5
			10.0			

Lat. left	51° 10′ N	Long. left	40° 19′ W
D. Lat.	10 S	D. Lo.	2 25 .5 E
Lat. in	51° 00′ N	Long. in	37° 53′.5 W

Course and distance made good E ½ S, 92 miles.

In taking out the Lat. and Dep. for 39.5 mi. we may take the Lats. and Deps. for 39 and for 40 and divide the sum by two; or we may take out the Lat. and Dep. for 39 and then for 0.5 mi. and add them. To find the Lat. and Dep. for 0.5 mi. take out the numbers for 5 mi. and point off, one place to the left.

The Dep. for the E course and the Lat. for the S course are not in the traverse table because the right triangle becomes a straight line and no calculation is necessary. When sailing East the Dep. is the same as the Dist. When sailing South the Lat. is the same as the Dist.

CURRENT

Whenever there is a current of known set and drift this should be included as one line of the traverse, because the ship is carried over this course and distance by the water just as though she sailed it as one of her courses. The courses and distances shown by the compass and log give her movement with reference to the water, but the movement of the water itself has carried her over the course and distance given by the set and drift of the current.

Example. Suppose a vessel in Lat. 42°, Long. 60°, sails N 45° W (true), 20 miles, in 2 hours, and is in a current which sets N 45° E, 2 miles per hour. The traverse for finding her change in Lat. and Long. would be as follows:

Course	Dist.	N	S	E	W	D. Lo.
N 45° E.......	20	14.1		14.1		
N 45° W.......	4	2.8			2.8	
		16.9		14.1	2.8	
				11.3		15.2

Lat. left.	42° 00′ N		Long. left	60° 00′ W
D. Lat.	16 .9 N		D. Lo.	15 .2 E
	42° 16′.9 N		Long. in	59° 44′.8 W

PROBLEMS

1. A vessel in latitude 36° 30′ N sails west 156.5 knots (nautical miles). Her longitude left was 60° 19′ W. What is the longitude in? *Ans.* 63° 34′ W.

2. A vessel in Lat. 61° N, Long. 30° W sails west 96 miles. What is the longitude in? *Ans.* 33° 18′ W.

3. A vessel in Lat. 40° N, Long. 30° W sails S 45° W 400 miles. What is her longitude? *Ans.* 35° 59′ W.

4. A vessel in Lat. 50° S, Long. 10° W sails SSW 290 miles. What is her longitude? *Ans.* 13° 01′ W.

5. A vessel in Lat. 39° 51′ N, Long. 49° 16′ W sails the following courses: S 45° E, 14 mi., S 72° E, 20 mi., N 68° E, 18 mi., N 76° E, 21 mi., N 89° E, 61 mi. Find Lat. and Long. in, and course and distance made good.
Ans. 39° 48′ N, 46° 30′ W, S 89° E, 127 mi.

6. A vessel in Lat. 46° 18′ N, Long. 31° 10′ W, sails NE 21 mi., ENE 8 mi., E by S 18 mi., S by E ½ E 12

mi., SSW 14 mi. Find Lat. and Long. and course and distance made good.

Ans. 46° 08′ N, 30° 15′ W, ESE ¾ E, 39 miles.

7. A vessel in Lat. 42° 00′ N, Long. 60° 00′ W, sails SE by S 29 mi., NNE 10 mi., ESE 50 mi., ENE 50 mi. Find her position and the course and distance made good.

Ans. 41° 45′.1 N, 57° 29′.3 W, E ¾ S, 113.7 mi.

8. A vessel in Lat. 34° 54′ N, Long. 136° 27′ W, sails S 18° W, 41 mi., S 80° W, 31 mi., N 85° W, 28 mi., N 56° W, 17 mi. Find her position and the course and distance made good.

9. A vessel in Lat. 49° 17′ N, Long. 35° 50′ W, sails N 65° E (by compass) variation 31° E, dist. 98 mi., S 69° E, var. 31° E, 110 mi., S 40° E, var. 30° E, 212 mi., S 10° W, var. 30° E, 40 mi. Find her position and the course and distance.

10. At noon, Lat. 48° 16′ N, Long. 30° 10′ W, a vessel's log reads 20.1 mi. The course is 165° by compass, error 5° E. At 1 P.M. log reads 38.6 mi. Course 160° (p.c.), error 6° E. At 3 P.M. log reads 74.0. Course 158°, error 6° E. At 4.30 P.M. log reads 85.6. Find the position by D.R. at $4^h\ 30^m$.

11. A vessel in Lat. 40° 00′ N, Long. 71° 00′ W runs, by compass, 170°, var. 11° W, dev. 5° E, 40 mi.; 210° (by compass), var. 10° W, dev. 3° W, 20 mi.; 250° (by compass), var. 9° W, dev. 1° W, 13 mi.; 271° (by compass), var. 9° W, dev. 3° E, 26 mi. Find position by D.R. and course and distance made good.

Ans. 38° 53′.6 N, 71° 41′ W.

12. A vessel in Lat. 40° 10′ N, Long. 35° 50′ W sails the following courses by compass:

Course	Variation	Deviation	Leeway	Tack	Distance, miles
40°	24° W	5° E	5°	Port	21
100°	24° W	1° W	3°	Starboard	17
190°	24° W	4° E	8°	Starboard	41
300°	24° W	3° W	3°	Port	29

Find position by D.R.

13. A vessel in Lat. 39° 51′ N, Long. 49° 16′ W runs 157° (p.c.), var. 22° W, dev. 3° E, wind 3°, 14 mi.; 128°, var. 22° W, dev. 4° E, wind 2°, Dist. 20 mi.; 91°, var. 22° W, dev 1° W, wind 0°, Dist. 18 mi.; 99°, var. 22° W, dev. 1° W, wind 0°, Dist. 21 mi.; 110°, var. 22° W, dev. 2° E, wind 1°, Dist. 61 mi. The wind is west, by compass. Find position by D.R.

14. A vessel sails N 30° W 42 mi., N 51° W 50 mi., due west 12 mi. During this time she was in a current which set N 60° E, 8 miles. What is her course and distance made good?

15. At 6^h A.M. Minots Ledge Light is 4 points off the starboard bow; log reads 90.0 mi. At 6^h 06^m A.M. Minots is abeam, bearing SSW; patent log reads 92.1 mi. At 6^h 06^m A.M. course is set at ESE, var. 13° W, dev. ½ pt. E; on this course ship runs 43 miles. At 8^h 20^m course is changed to S 30° E, var. 14° W, dev. 1° E, run 20 miles. At 9^h 20^m course is set at S 15° W, var. 14° W, dev. 1° W, run 47 miles, to noon. At noon

course is set at 210°, var. 12° W, dev. 1° W, run 150 miles. At 7 P.M. course is changed to 212°, var. 9° W, dev. 2° W, run 200 miles to 8 A.M. Find the Lat. and Long. by D.R. at noon and also at 8 A.M. The position of Minots is Lat. 42° 16′ 11″ N, Long. 70° 45′ 35″ W.

Ans. Noon $\begin{cases} 41° \ 07' \ 41'' \text{ N} \\ 69° \ 30' \ 05'' \text{ W} \end{cases}$ 8 A.M. $\begin{cases} 35° \ 37' \ 35'' \text{ N} \\ 71° \ 57' \text{ W} \end{cases}$

LAYING OUT A COURSE

If the distance to be run is not very great (say 400 miles), and especially if the course is nearly east or west, we may employ middle latitude sailing for laying out a course. For long distances and in high latitudes, especially with courses running more nearly north and south, Mercator sailing should be used. Whenever the Mercator track is considerably longer than the great-circle track between the points of departure and destination, great-circle sailing may be used to save distance.

MIDDLE LATITUDE SAILING

Suppose that we wish to know the course and distance to sail from a point in Lat. 30° 20′ N, Long. 71° 25′ W to a point in Lat. 32° 20′ N, Long. 65° 10′ W.

Take the difference of latitudes and the difference of longitudes; then turn the D. Lo. into Dep. by reversing the rule previously given, that is, on the page of Table 2 containing the degrees of the middle latitude look for the D. Lo. in a Dist. column; the number abreast of this in the Lat. column is the

Dep. sought. To find the true course and distance to sail look in Table 2 (or Table 1, if desired) and find this D. Lat. and Dep. on the same line. The course and distance corresponding are the ones required.

The true course must be converted into a compass course by applying the variation and deviation. Our example would then be worked out as shown on p. 60.

If the distance is so great that the traverse tables will not give the result directly, it will be convenient and more accurate to use logarithms. To find the logarithm of the departure (log Dep.) add the log D. Lo. to the log cosine of the middle Lat. The log D. Lo. is in Table 42, the first three figures of D. Lo. being in the left-hand column and the fourth figure at the top of one of the columns. The number in the table is the decimal part of the logarithm. At the left of the decimal we must write in a number called the *characteristic* or *index*. This is a number which is always **one less** than the number of figures in the D. Lo. For instance if the D. Lo. is 1206′ the characteristic is 3; if the D. Lo. is 120′ the characteristic is 2. The log cosine of the middle Lat. is found in Table 44, the degrees being at the top and the minutes at the left, unless the Lat. is greater than 45°, in which case the degrees are at the bottom and the minutes on the right. If the degrees are at the top the word cosine is at the top; if the degrees are at the bottom the word cosine will be found at the bottom of the page.

To find the course (*C*), subtract log D. Lat. from log Dep. Log D. Lat. is found in Table 42, just as described

MIDDLE LATITUDE SAILING

Departure*	30° 20′ N		71° 25′ W
Destination	32° 20′ N		65° 10′ W
D. Lat. =	2° 00′ N	D. Lo. =	6° 15′ E
=	120′	=	375′ = 321.4 mi. Dep.
Mid Lat. =	31° 20′		
(true) Course =	N 70° E	Dist. =	342 mi.
=	70°		

* The word departure is used here to denote the position left; it should not be confused with Dep., the distance east or west.

for log D. Lo. This gives the log tangent of the course (log tan C). To look up C, enter Table 44 and look in the column marked "tangent." The degrees and minutes corresponding to the nearest logarithm in the table will be the required course. The arrangement of the table of tangents is like that described for cosines.

To find the distance add the log cosecant of the course (log csc C) to the log Dep. Look in Table 42 for the number corresponding to this log. Remember that if the characteristic is 2, there will be three figures in the number of miles, always one greater than the characteristic.

Example. Lat. left, 42° 20′ N, Long. left, 70° 45′ W; Lat. dest., 43° 00′ N, Long. dest., 50° 00′ W. Find course and distance.

$$\begin{aligned}
\text{D. Lo.} &= 20^\circ\ 45' = 1245' \\
\text{middle Lat.} &= 42^\circ\ 40' \\
\text{D. Lat.} &= 40' \\[6pt]
\log \text{D. Lo.} &= 3.09517 \\
\log \cos \text{mid. Lat.} &= \underline{9.86647} \\
\log \text{Dep.} &= 2.96164 \\
\log \text{D. Lat.} &= \underline{1.60206} \\
\log \tan C &= 1.35958 \\
C &= (\text{N})\ 87^\circ\ 30'\ (\text{E}) \\[6pt]
\log \text{Dep.} &= 2.96164 \\
\log \csc C &= \underline{0.00041} \\
\log \text{Dist.} &= 2.96205 \\
\text{Dist.} &= 916'.3
\end{aligned}$$

After we have found the angle between the course and the meridian (between 0° and 90°) we may write it as a

course in the 360° system, because we know which quadrant the course is in. For example, if the angle (C) found in the table is 30°, and the course is between N and W, it is written 330°.

MERCATOR SAILING

The length of the degrees on Mercator's chart are increased according to the latitudes. The number of miles in these increased latitudes is given in Bowditch, Table 3. These are called "meridional parts." Problems in Mercator sailing that can be worked out by chart may be solved still more accurately by the use of this table. There are two cases that arise under Mercator sailing.

(1) Given the Lat. left and Long. left and the course and distance sailed, to find the Lat. and Long. in. In this case the new Lat. may be found by the ordinary method, using the traverse tables.

Having found the new latitude, take from Table 3 the meridional parts for the two Lats. If the Lats. are in the same hemisphere (both N or both S) subtract the less from the greater. The difference is called *m*. To find the D. Lo. multiply *m* (the increased D. Lat.) by the tangent of the course.

To do this by logarithms add the log of m to the log tan of the course (log tan C). The result is the log of the D. Lo. To find log m look in Table 42; the first three figures of m will be found in the left-hand column, and the fourth figure at the top (or bottom) of the page. To correct the log given in the table for the 5th figure

in *m*, look in the marginal table at the right; opposite the 5th figure is the correction to be added. When there are several marginal tables use the one corresponding to the difference of the two nearest logs in the table. Log tan *C* (course) will be found in Table 44, the degrees being at the top and the minutes in the left column, unless the angle is greater than 45°, in which case the degrees are at the bottom and the minutes on the right. The correction to be added for seconds is found by calling the left-hand minute column "seconds" and looking in the column marked "Diff." which is next to the column of tangents.

Example. Lat. in, 40° 00′ N, Long. in, 31° 00′ W. Course S 31° W, Dist. 660 mi.

	Lat. left	40° 00′ N	Mer. Pts.	2607.6
By Table 2	D. Lat.	9° 25 .8 S		1916.0
	Lat. in	30° 34′.2 N	*m*	691.6
	Lo. left	31° 00′ W	log *m*	2.83985
	D. Lo.	6 55 .5 W	log tan *C*	9.77877
	Lo. in	37° 55′.5 W		2.61862
			D. Lo.	=415′.5
			(Table 42)	
				=6° 55′.5

EXPLANATION

In taking out the meridional parts for 30° 34′.2 we take first the number for 30° 34′ which is 1915.8; then adding to this a correction equal to two tenths of the difference between 1915.8 and 1917.0, that is 0.2 × 1.2 = 0.24, we obtain 1915.8 plus 0.2 = 1916.0.

The log of *m* is found on line of 691 and in column

marked 6 at the top. Suppose there had been another figure, 4 (that is, $m = 691.64$); to find how much to increase the log for this 4 we look in the little table at the right and find opposite 4 the number 2, which should be added to the log already found, giving 2.83987. The number to the left of the decimal point in the logarithm of m is the characteristic. It is not given in the table but must be written in afterward. It is always one less than the number of figures to the left of the decimal point in m; that is if m had contained but two figures (as 69.2) the characteristic of the log would have been 1.

The log tan C is found on the page marked 31° (at the top) and on the line marked 0′ at the left. Let us suppose there had been 15″ more (S 31° 00′ 15″ W), we should then look in the column marked Diff., next column to the right, and opposite 15, we find 7, which added to the log tan C already found gives 9.77884. It is not necessary in practice to work to seconds in Mercator sailing.

(2) The second case arising under Mercator sailing is when the Lat. and Long. of the point of Departure and the Lat. and Long. of the Destination are given, and the course and distance are to be found.

In this case take the difference of the latitudes, the difference of the longitudes, and the difference of the meridional parts (m), if both lats. are N, or both are S. Subtract the log of m from the log D. Lo. (Table 42). The result is the log tan C; find the course (C) from Table 44 as described on p. 63, then add the log secant C to the log D. Lat. and the result is the log of the distance.

MERCATOR SAILING

Lat. left	47° 30′ N	Mer. pts.	3229.6	Long. left	52° 45′
Lat. of Dest.	35 57 N	(Table 3)	2300.5	Long. of Dest.	5 45
D. Lat. =	11° 33′	m =	929.1	D. Lo. =	47° 00′
=	693′			=	2820′

log D. Lo.	3.45025	log D. Lat.	2.84073
log m	2.96806	log sec C	0.50457
log tan C	0.48219	log dist.	3.34530
(true) Course =	S 71° 46′ E	Dist. =	2215 miles
=	108° 14′		

Take out log sec *C* while you have the page open from which you find *C*. Sec *C* will be on the same line as tan *C*, already found. This will be made clearer by an example.

Example. Find the course and distance from a point in Lat. 47° 30′ N, Long. 52° 45′ W to a point in Lat. 35° 57′ N, Long. 5° 45′ W. (See page 65.)

PROBLEMS

1. Find the course and distance from 40° 40′ N, Long. 51° 35′ W to 50° 50′ N, 10° 55′ W.

Ans. Course N 70° 16′ E, 1807 mi.

2. Find the course and dist. from 13° 10′ N, 59° 30′ W to 36° 00′ N, 5° 33′ W.

Ans. Course N 54° 34′ E, 3235.6 mi.

3. Find course and dist. from 56° 40′ N, 59° 00′ W, to 51° 00′ N, 10° 00′ W.

4. Find course and distance from 55° 15′ N, 59° 00′ W to 37° 00′ N, 8° 55′ W.

GREAT-CIRCLE SAILING

In sailing over a great-circle track, in order to make the shortest distance, we need to know the course at each point along track and also the total distance to be run. The track may be transferred from the great-circle chart to the Mercator chart by taking off the latitudes and longitudes of several points (see Figs. 13 and 14). The courses and distances between these points may be found from his chart by Mercator sailing. The course from any

point on the track to the point of destination may be found quickly and with sufficient accuracy by means of the tables of the Sun's Azimuth (Hydrographic Office Publ. No. 71).* These tables are calculated to give the azimuth (or true bearing) of the sun when the Lat. of the observer, the declination of the sun, and the local apparent time are known. But if we call the Lat. of the point of departure the *Lat.*, and call the Lat. of the destination the *sun's decl.*, and for the D. Lo. use the *apparent time*, then the resulting Azimuth will correspond to the course to be steered along the great circle. This course may be taken out each time the course is to be altered, say, at each watch, or each day, according to speed. The final course may be found by interchanging the Lat. and Decl. in the tables. (See p. 129 for use of these Tables.)

The method of computing these courses by logarithms may be found on p. 81, Bowditch's *Navigator*.

The length of the track may be found by adding together the log sin D. Lo., the log cos Lat. (of point of dep.) and the log cosec of final course. The sum is the log sin Dist. This Dist. (which will be in degrees and min.) must be changed into minutes to get the distance in nautical miles.

All of the logarithms mentioned will be found in Table 44. The log sines, cosines, secants and cosecants are taken from Table 44 in the same way as tangents,

* If the Lat. of Dest. is greater than 23° it will be necessary to use H. O. Publ. No. 120, which gives Azimuths of stars. In this table use "Hour Angle" in place of "Apparent Time."

except that it must be remembered that cosines and cosecants decrease when the angle increases, so the correction for seconds is subtracted. The cosecant will have a characteristic of 10; this may be dropped when adding the logs.

Example. Find the initial course, final course, and distance from Lat. 55° 18′ N, Long. 59° 00′ W to Lat. 51° 00′ N, Lo. 10° 00′ W.

From H. O. Publ. 120, using Lat. 55° 18′ N, Decl. 51° 00′ N (Lat. of Dest.), and Hour Angle $3^h\ 16^m$ (= 49° = D. Lo.),* we find for the Az., N 77° 48′ E which is the course at the start. Using Lat. 51°, Decl. 55° 18′, and Hour Angle $3^h\ 16^m$, the final course is S 62° 09′ E. The distance is then found as below.

D. Lo.	49° 00′	log sin	9.87778
Lat.	55° 18′	log cos	9.75533
Final *C*	62° 24′	log csc	0.05346
		log sin Dist.	9.68657
		Dist. 29° 04′ = 1744 miles (nearly)	

If the number of degrees in the final course is less than the number of degrees in the initial course it will be a little more accurate to take the cos Lat. left and cosec of initial course, and add these to the log sin D. Lo.

PROBLEM

Find the initial and final courses and the length of a great-circle track from Lat. 13° N, Long. 59° W to Lat. 36° N, Long. 6° W.

Ans. N 54° 22′ E; N 78° 11′ E; dist. 3159 miles; change of course, about 1° for every 132 miles.

* See p. 83 for method of changing degrees into hours.

CHAPTER VI

NAVIGATION BY OBSERVATION

Instruments used — Sextant

NAVIGATION by observation consists in determining the position of the ship by measuring the altitude of the sun, moon or stars, and calculating the latitude and longitude. The altitude is the number of degrees, minutes and seconds that the center of the sun, moon or star is above the true horizon. This angle is found by means of the sextant.

The sextant is an instrument designed for measuring the angle between two visible objects; it is necessary therefore to measure the altitude of the sun or star above the sea-horizon instead of the true horizon.

The sextant (Fig. 23) consists of a frame carrying a graduated arc, or limb (*AB*), divided into degrees and usually ten-minute spaces. In some instruments the degrees are divided into 20-minute spaces, and in some into 30-minute spaces. The index-arm (*IE*) is pivoted at the center of the arc; at its lower extremity it carries a short arc marked with a vernier, The index, or 0-mark of this vernier, is the mark which shows on the limb the angle which has been measured. The index-arm may be clamped in any position by a screw (*C*) at the back and then may be moved slowly over small arcs by means

of the tangent screw, or slow-motion screw, (*T*). On the index-arm, over the pivot, is a mirror called the index-glass (*I*). At the front of the instrument is the horizon-glass (*H*), the right half of which is silvered; the left

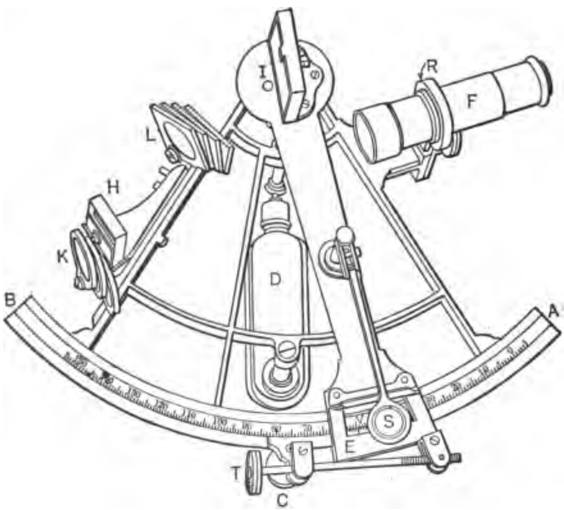


FIG. 23.

half is plain glass. Two sets of colored glass shades (*L*) and (*K*) are provided for making observations on the sun.

To measure an altitude of the sun move one of the colored shades (*L*) into line between the two mirrors, hold the instrument in the right hand, direct the line of

sight (as shown by the telescope (*F*) and the horizon-glass) to that point of the horizon directly beneath the sun, move the index-arm out from 0°, away from the observer, until the reflected image of the sun is seen in the horizon-glass. Focus the telescope carefully. Set the index-arm so that the lower edge of the sun touches the horizon as shown in Fig. 24. This contact may be made perfect by setting the clamp tight, then moving

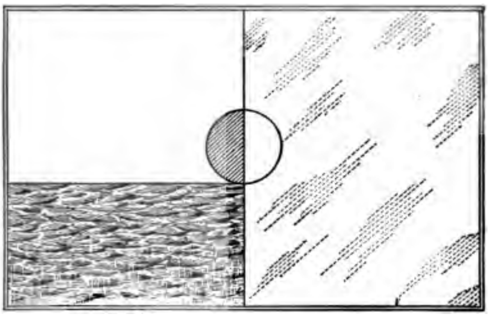


FIG. 24.

the tangent screw until the edge of the disk just touches the horizon. The contact should now be tested by tipping the sextant to right and left in such a way as to cause the sun to "sweep the horizon," that is, it will move from side to side and will rise above the horizon on either side of the central position (Fig. 25). If it goes below the horizon at any point the angle is too great and the tangent screw should be moved until the sun just touches the horizon at one point during the swing.

In sighting the sun it will be noticed that if the sextant is turned to the left so as to make the sun's image fall on the mirror, the sun's image is brighter but the horizon cannot be seen directly under it because it is obscured by the silver. If the sextant is turned to the right the sun can be seen reflected from the plain glass and at the

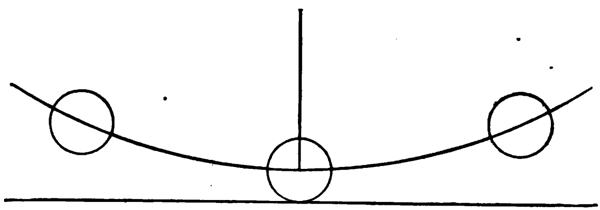


FIG. 25.

same time the horizon can be seen under it. The angle will be more accurate if the contact is made when the sun is on the edge of the silvered portion, as shown in Fig. 24, which should be about in the center of the telescope.

It is advisable for the beginner to take his first sights without any telescope because he can see better what he is doing. The plain sight tube will give more accurate results by confining the observation to the central part of the mirror. After good sights can be taken with the plain tube it will be an easy step to observe with the telescope.

The altitude is next read from the arc by first noting the degrees and the ten-minute marks that have been

passed over by the index-mark. Fig. 26 shows the division of the limb into degrees and 10′ spaces, and Fig. 27 shows the appearance of the vernier and limb

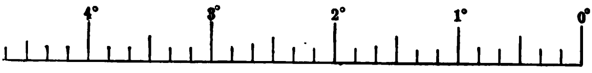


FIG. 26.

when the index is set to read 0°. When an altitude is taken the index-mark will usually be found to have passed a little beyond some mark on the limb. In Fig.

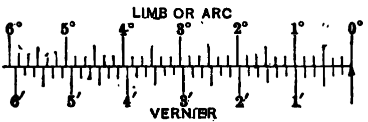


FIG. 27.

28 the index has moved over 2° 40′ and a little more. To read this additional number of minutes beyond the last 10′ mark, look along the vernier to the left and find

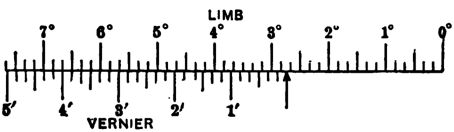


FIG. 28.

the number of the graduation which is exactly in line with some graduation on the limb. The 10″ vernier has long lines for the minutes, shorter ones for the 30″ and still shorter lines for the 10″ divisions. In Fig. 28, the

4′ 10″ line just coincides with a line on the arc. The total altitude therefore consists of two parts, the reading of the arc and the reading of the vernier. These two added together give 2° 44′ 10″, the observed altitude. This altitude must be corrected for Index Error, as explained later.

ADJUSTMENTS OF THE SEXTANT

1. Set the index to read about 60° on the arc. Look in the index-glass and see if the reflected image of the limb appears to be a continuation of the actual limb. If there is a break in the line it shows that the mirror is tipped forward or backward. By turning a screw in the back of the frame of this mirror it may be tilted until the line of the arc is continuous. This shows that the plane of the mirror is perpendicular to the plane of the graduated arc.

2. (a) Set the index to read 0°. Hold the sextant face upward, but slightly tilted, and sight toward the horizon, or better still sight toward a definite point like a bright star, or the ball on a distant flag pole. If the reflected image appears to be above or below the object as seen directly the mirror is tipped, and the screws at the back should be turned until the object and its image coincide.

2. (b) With the index set at 0°, hold the sextant vertically, as when taking the sun, and examine the horizon. If the horizon and its image do not coincide the proper adjusting screws should be moved until they do. If it is not desired to alter the adjustment, move the tangent screw until the images coincide. The reading

of the index is then the *Index Correction* (I. C.), or the amount to be added to or subtracted from every reading of the sextant to obtain the correct angle. If the index is to the left of 0° the I. C. is marked − and is to be taken off every reading. If the index is to the right of 0° it is marked + and is added to the sextant reading to obtain the correct angle.* If the index is to the right of 0° the amount of the I. C. may be read in either of two ways. (1) We may read the vernier as usual and then subtract from 10′, obtaining the amount by which the index has passed to the right of 0° or to the right of the last division it passed. (2) We may begin at the left end of the

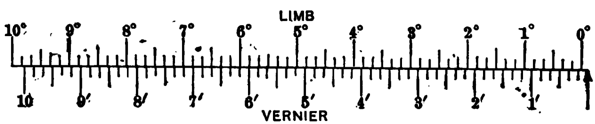


FIG. 29.

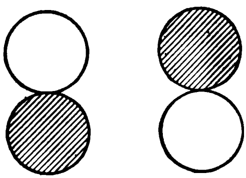
vernier and, disregarding the actual numbers, count off the minutes and 10″ spaces. In Fig. 29 the vernier reads 6′ 30″, but the I. C. is + 3′ 30″. The index correction may also be found by observing the sun, as described later.

3. Sight over the plane of the instrument while it is resting on a table, and make a mark in this plane on a wall 20 ft. or more away. Allow for the height of the telescope above this plane. Sight through the telescope

* Or, according to the old rule, "When it's on it's off and when it's off it's on."

and see if this point comes in the center of the field of view. If not, tip the telescope by means of the adjusting screws until the point is in the center of the field of the telescope.

To find the index correction from the sun: Set the index near 0°, use colored shades in front of the horizon-glass as well as below the index-glass. Choose different colors for the two. Then look directly at the sun and bring the image of the sun's limb into contact with the limb as viewed directly (*a*, Fig. 30). Read the vernier. Then move the image across so as to be in contact at the opposite edge (*b*, Fig. 30). Read the vernier. The vernier reading which is off the arc (about 32′) should be marked +; the reading on the arc is marked −. Take the difference between the two readings, divide by 2, and mark the result with the sign of the greater reading. This gives the Index correction.



(*a*) (*b*)

FIG. 30.

PROBLEM. The index correction is found by observation on the sun as follows: reading off the arc, 31′ 45″; reading on the arc, 31′ 25″. What is the I. C.?

Ans. +10″.

THE CHRONOMETER

The longitude of the ship depends upon the Greenwich time, and this is shown by the chronometer carried on the ship. The chronometer is, for this reason, one of the

most important of the instruments used, and great care should be exercised to see that it is kept running at a uniform rate. A second reason for carrying a chronometer is that in making his calculations the navigator must use the Nautical Almanac and this requires a knowledge of the Greenwich time.

The chronometer is an accurately made timepiece, hung in gimbals and set and regulated to keep mean solar time at the meridian of Greenwich (observatory), England. It is wound regularly once a day at some specified time. It should be kept in a special box, carefully protected from sudden changes of temperature, from magnetic influences, and from any jarring of the engines. The navigator should ascertain its error at some definite date and the daily rate at which it is gaining or losing, so that he may be able to calculate its error at any time it is required.

RATING THE CHRONOMETER

The sea-going rate of a chronometer is not usually the same as the rate determined when the chronometer is on shore. In order to find the rate at sea the navigator should take pains to make an observation for local time when at some point of known longitude (by methods to be given later), from which he may calculate the Greenwich Mean Time and thence the error of the chronometer. If in a port where a time ball can be observed he may get the Greenwich Mean Time directly. A time signal may also be obtained by wireless if the ship carries wireless apparatus. The gain or loss between two such obser-

vations divided by the number of days gives the daily rate. If the chronometer is fast the chronometer correction is marked −, if slow it is +. When it is gaining the rate is marked −, if losing it is +.

Example. Suppose that at New York the chronometer time when the time ball dropped was $4^h\ 59^m\ 10^s$ on Sept. 15. The time ball drops at noon, Eastern Standard Time, or $5^h\ 00^m\ 00^s$ P.M. Greenwich Mean Time; so the chronometer is 50^s slow. Again suppose that when the ship is South of Cape Clear (Lo. 9° 29′ 03″ W) the G. M. T. is found by observation to be $3^h\ 56^m\ 27^s$ P.M. on Sept. 24, at which time the chronometer reads $3^h\ 55^m\ 47^s$. At the second observation the chronometer is 40^s slow. Then we have for the rate,

$$\begin{array}{lrl} & \text{Sept. } 15 & \text{C. C.} = +50^s \\ & \text{Sept. } 24 & \text{C. C.} = +40^s \\ \hline \text{Diff.} & 9^d & \text{Gain} = \quad 10^s \end{array}$$

$$\text{Daily rate} = \frac{10^s}{9} = -1^s.1$$

COMPARISON OF CHRONOMETER AND WATCH
C − W

The chronometer should not be moved from its position. In order to take the time when sights are made an observing watch is often used. This watch is compared with the chronometer just before or just after the sight is taken. The error of the watch does not enter into the final result because we use the watch only for measuring the short interval between the observation and the comparison. The comparison is made as follows:

Compare the chronometer and the watch and take the difference between the two. If the watch reading is less than the chronometer reading mark the difference +, if greater mark it −. This correction, called the C − W, is to be added to or subtracted from the watch time of sight to obtain the chronometer time of sight. In making this comparison it is not necessary to look at the chronometer at the instant; the ticks of the chronometer may be counted mentally while the eye follows the second-hand of the watch.

Example:

Chro.	$1^h\ 29^m\ 00^s$
Watch	$9^h\ 51^m\ 27^s$
C − W =	$-8^h\ 22^m\ 27^s$

This time interval subtracted from the watch time of the sight will give the chronometer time of the sight.

If the observing watch is kept regulated to G. M. T. and its correction obtained frequently, it will be unnecessary to apply the C − W correction.

On small vessels the time is often noted directly on the chronometer, a signal of some sort being used to notify an assistant when to take the time.

HACK CHRONOMETER

When the ship carries several chronometers it is customary to use also a cheaper chronometer, called the "hack," which may be carried to any convenient place for use in observing, but is usually kept in the chart-house. The time of sights is not taken directly on the hack chronometer, but the observing watch is compared

with the hack as already explained. The error of the hack on Greenwich Mean Time is found by daily comparison with the other chronometers, the mean result for all the chronometers being taken as true G. M. T.

PROBLEM

On July 12 at noon, Eastern Standard Time, Chronometer is fast $1^m\ 32^s.3$ by the time ball. On July 19 at noon (E. S. T.) the chronometer is $1^m\ 29^s.0$ fast by the time ball. What is the daily rate? What is the C. C. on Aug. 1 at noon?

Ans. $+ 0^s.47$; $- 1^m\ 22^s.9$.

CHAPTER VII

MEASUREMENT OF TIME — THE NAUTICAL ALMANAC — CORRECTING THE ALTITUDE

TIME

It is important that the navigator should understand the different kinds of time employed in astronomical calculations, and the methods used in changing from one kind of time to another.

ASTRONOMICAL AND CIVIL TIME

The time given in the Nautical Almanac is always *Astronomical*, that is, the instant of noon is called 0^h and the hours are counted continuously up to 24^h. *Civil time* is the ordinary system in which the day is divided into two parts; from midnight to noon is called A.M. and from noon to midnight is called P.M. The Astronomical day begins at noon of the civil day of the same date, so that during the P.M. the hours and the date are the same for the two kinds of time. If it is A.M. the hours of the Astronomical time are 12 more than the hours of the civil time but the date itself is one day less.

Hence to change from civil to astronomical time we have the following rule: if the civil time is A.M. add 12^h and subtract one day, and drop the letters A.M.; if the civil time is P.M. simply drop the letters P.M.

Many chronometers show but 12^h on the dial, like ordinary watches; in this case it is necessary to add 12^h to the actual chronometer reading if the time is A.M. and astronomical time is desired.

MEAN AND APPARENT SOLAR TIME

Apparent Solar Time is the time given by the sun, such as would be read directly from a sun dial, or the time calculated from an observed altitude of the sun. It is 0^h or noon, apparent time, when the sun is on the meridian, that is, when the sun's center bears true north or south. This kind of time is not uniform throughout the year on account of the variation in the sun's apparent motion. *Mean Time* is time based on the average length of the solar day and is the time kept by all watches and chronometers. All the mean solar days are of exactly the same length. The accumulated difference between the two kinds of time at any date is called the *Equation of Time* and is given in the Nautical Almanac. If the equation of time is to be added to mean time to give apparent time it is marked +; if it is to be subtracted from mean time it is marked −.

STANDARD TIME

Standard Time is a system of time used in the United States for convenience in Railroad transportation. It is based upon Greenwich Mean Time. In the Eastern Time Belt the time is that of the 75° meridian (west), or 5^h slow of Greenwich; in the Central Time belt it is 6^h slow of Gr.; in the Mountain Time belt it is 7^h slow of Gr.; and in the Pacific Time belt it is 8^h slow of Gr.

LONGITUDE AND TIME

Longitude is counted from the meridian of Greenwich (England), either to the east or to the west, and is measured in degrees, as shown on the charts. It may also be expressed in units of time, that is, in hours, minutes, and seconds. The earth turns through 360° in 24^h of time, or 15° for each hour of time. Consequently, the difference in longitude between any two meridians may be expressed either as the number of degrees difference in longitude, or as the number of hours, min., and sec. difference in their local times. If two places are 15° apart in longitude the local time at any instant will always be 1^h later at one place than at the other.

To change degrees into hours: **Divide the degrees by 15 and call the result hours; multiply the remainder by 4 and call it minutes. Then divide the minutes by 15, call the result minutes; multiply the remainder by 4 and call it seconds; divide the seconds by 15 and call the result seconds.**

Example. Change 116° 41′ 50″ into time.

$15\overline{)116^\circ}$

7^h and 11° remainder

$11^\circ \times 4 = 44^m$ $\qquad 7^h\ 44^m$

$15\overline{)41'}$

2^m and $11'$ remainder

$11' \times 4 = 44^s$ $\qquad 2^m\ 44^s$

$15\overline{)50''}$

$3^s\frac{1}{3}$ $\qquad 3^s\ \frac{1}{3}$

Result $\qquad 7^h\ 46^m\ 47^s\ \frac{1}{3}$

To change hours, min., and sec. into degrees, reverse the preceding process.

Example. Change $4^h\ 29^m\ 54^s$ into degrees, min., and sec.

$$
\begin{array}{rl}
4^h \times 15 = & 60^\circ \\
\dfrac{29^m}{4} = & 7^\circ \text{ and } 1^m \text{ remainder} \\
1^m = & 15' \\
\dfrac{54^s}{4} = & 13' \text{ and } 2^s \text{ remainder} \\
2^s \times 15 = & \underline{30''} \\
\text{Result} & 67^\circ\ 28'\ 30''
\end{array}
$$

These results may be found by means of Table 7, Bowditch. They may also be found conveniently by Table 45. But having once mastered the above process the change is made about as quickly without tables. It will be well to memorize the following.

$$
\begin{array}{rl}
15^\circ & = 1^h \\
15' & = 1^m \\
15'' & = 1^s \\
1^\circ & = 4^m \\
1' & = 4^s
\end{array}
$$

Care should be used in distinguishing the two kinds of minutes and seconds. Use the *m* and *s* for the min. and sec. of time only.

SIDEREAL TIME

Sidereal time is used when observing the stars. It is 0^h (or what corresponds to noon in solar time) when the

vernal equinox* is on the meridian. Sidereal time may be found from mean time by adding the *Right ascension of the Mean Sun* in the same way that Apparent time is found from mean time by adding or subtracting the equation of time.

To change Greenwich Mean Time into Greenwich Sidereal time, **add together the G. M. T., the Rt. Asc. of the Mean Sun (at G. M. N.), taken from the Nautical Almanac, and the correction from the tables at the foot of the page taken out for the number of hours in the G. M. T. If *local* sidereal time is required, subtract the west longitude from the Greenwich Sidereal Time. If the longitude is east, add it to the Greenwich Sidereal Time.**

NAUTICAL ALMANAC

The Nautical Almanac (N. A.) is issued for each year (in advance) by the Government and contains data that is necessary for solving the problems of nautical astronomy. The student should examine the Almanac carefully and understand its arrangement and the various terms employed.

The following table is an extract from the page giving the sun's *declination* and the *equation of time* for the month of November, 1917. This part of the Almanac is the one most frequently used by the navigator.

* The vernal equinox is the point on the equator where the sun's center crosses it (about March 21) when going north.

SUN, NOVEMBER 1917

G. M. T.	Sun's Declination	Equation of Time	Sun's Declination	Equation of Time
	Thursday 1		Monday 5	
h	° ′	m s	° ′	m s
0	−14 20.6	+16 20.0	−15 35.9	+16 20.7
2	14 22.2	16 20.1	15 37.4	16 20.5
4	14 23.8	16 20.3	15 38.9	16 20.4
6	14 25.4	16 20.4	15 40.5	16 20.2
8	14 27.0	16 20.5	15 42.0	16 20.1
10	14 28.6	16 20.7	15 43.5	16 20.0
12	14 30.2	16 20.8	15 45.0	16 19.8
14	14 31.8	16 20.9	15 46.5	16 19.6
16	14 33.4	16 21.0	15 48.0	16 19.5
18	14 35.0	16 21.1	15 49.6	16 19.3
20	14 36.6	16 21.2	15 51.1	16 19.1
22	14 38.2	16 21.3	15 52.6	16 18.9
H. D.	0.8	0.1	0.8	0.1
	Friday 2		Tuesday 6	
0	−14 39.8	+16 21.4	−15 54.1	+16 18.7
2	14 41.4	16 21.5	15 55.6	16 18.5
4	14 42.9	16 21.5	15 57.1	16 18.3
6	14 44.5	16 21.6	15 58.6	16 18.1
8	14 46.1	16 21.7	16 0.1	16 17.9
10	14 47.7	16 21.7	16 1.6	16 17.7
12	14 49.3	16 21.8	16 3.1	16 17.5
14	14 50.9	16 21.8	16 4.6	16 17.2

*To take out the sun's declination** for any hour and minute of G.M.T.: The sun's declination is given for every 2^h of the day, beginning at noon, or 0^h; so we may

* The sun's declination is the number of degrees the sun is N or S of the equator.

take out the declination for the last preceding hour given and correct it as follows: multiply the H. D. (hourly difference) by the hour and fraction since the hour stated in the N. A. Add or subtract this according as the declination is increasing or decreasing.

Example. Find the declination of the sun at $3^h\ 30^m$ G. M. T. Aug. 1, 1917.

From the N. A. we have:

G. M. T.	Decl.	Equa. of Time
0^h 2 4	$+18°\ 06'.6$ $18\ \ 05\ .4$ $18\ \ 04\ .1$	$-6^m\ 10^s.3$ $6\ \ 10\ .1$ $6\ \ 09\ .8$
H. D.	$0'.6$	$0^s.1$

$$
\begin{aligned}
\text{The Declination at } 2^h &= +18°\ 05'.4 \\
\text{Interval since } 2^h = 1^h\ 30^m &= 1.5^h \\
1^h.5 \times 0'.6 &= \underline{\qquad 0'.9} \\
\text{Declination at } 3^h\ 30^m &= +18°\ 04'.5
\end{aligned}
$$

This might have been found by working backward from the Declination at 4^h:

$$
\begin{aligned}
\text{Decl. at } 4^h &\quad +18°\ 04'.1 \\
\text{Interval before } 4^h = 30^m &= 0^h.5 \\
0^h.5 \times 0'.6 &= \underline{\qquad 0\ .3} \\
\text{Decl. at } 3^h\ 30^m &= +18°\ 04'.4
\end{aligned}
$$

The second result is a little more accurate than the first because the time interval is shorter. It is always

more accurate to work from the nearest value given in the table.

The + sign means that the sun is North of the equator. When the sun is South, the Decl. is marked −. The sun is North from March 21 to Sept. 22, and South the rest of the year.

When using the sun's Decl. for the purpose of finding latitude or longitude it is convenient to change the tenths of minutes to seconds. Each tenth of a minute is equal to 6 seconds (6″); $0'.1 = 6''$, $0'.2 = 12''$, etc.

To take out the equation of time. Suppose we wish the equation of time for $3^h\ 30^m$ Aug. 1, 1917.

$$\begin{array}{rr} \text{Eq. time for } 4^h & -6^m\ 09^s.8 \\ \text{Interval, } 30^m = 0^h.5 & \\ 0^h.5 \times 0^s.1 = & \underline{\quad .1} \\ \text{Equa. time at } 3^h\ 30^m = & -6^m\ 09^s.9 \end{array}$$

It is stated at the foot of the page in the N. A. (Nautical Almanac) that the − sign means subtract the Equation of time from the G. M. T. to obtain Greenwich Apparent Time (G. A. T.).

Example:

$$\begin{array}{rl} \text{G. M. T.} = & 3^h\ 30^m \\ \text{Eq. t.} & \underline{\quad -6\ \ 09^s.9} \\ \text{G. A. T.} = & 3^h\ 23^m\ 50^s.1 \end{array}$$

To find Mean time from the Apparent time the process must be reversed, and the equation of time must be **added** to Apparent time if marked −.

The N. A. also contains tables giving data for the moon, planets, and stars. The arrangement and use

of these tables is similar to that described for the sun's declination. These will be explained in other chapters.

CORRECTING THE OBSERVED ALTITUDE

Before the observed altitude of the sun can be used for calculating latitude or longitude it must be corrected for the Index Error of the sextant (already mentioned), for the dip of the sea-horizon below the true horizon, for the effect of refraction and of parallax, and for the semi-diameter of the sun.

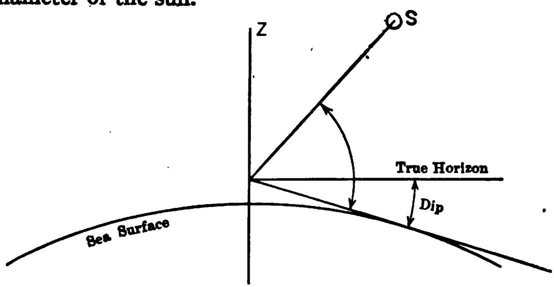


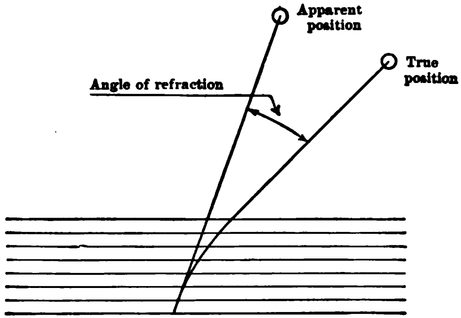
FIG. 31.

The sea-horizon is always below the true horizon by an amount which depends upon the height of the observer's eye above the water surface (Fig. 31).

The number of minutes and seconds by which the sea-horizon dips below the true horizontal line may be taken from Table 14, Bowditch. This correction must be subtracted from the measured altitude. Since the height of eye must be known for each observation the

navigator should determine beforehand the height of different parts of the vessel above the water surface by measuring with a tape.

The correction for refraction is made necessary by the fact that the rays of light from the observed object are bent into a curve when passing through the atmosphere, making the object appear to the observer to be higher above the horizon than it really is (Fig. 32). The



ATMOSPHERIC REFRACTION

FIG. 32.

amount of this correction for different altitudes may be taken from Table 20A, Bowditch. The correction for refraction is nothing for a point overhead, about 1′ for an altitude of 45°, and more than half a degree at the horizon. This correction is always subtracted from the measured altitude.

The parallax correction is a slight change in the apparent direction of the object due to the fact that the

CORRECTING THE ALTITUDE

Dip, Table 14	$-5' \, 53''$	Semi. diam.	$+15' \, 54''$
Refraction, Table 20A	$-1 \quad 53$	Parallax, Table 16	$8''$
I. C.	$-0 \quad 20$		$+16' \, 02''$
	$-8' \, 06''$		$- \; 8' \, 06''$
		Corr. =	$+ \; 7' \, 56''$

Obs. alt. $\odot$	$27° \, 12' \, 30''$
Corr.	$+ \; 7 \quad 56$
h	$27° \, 20' \, 26''$

observer is on the surface instead of at the earth's center, to which point all observations are reduced. The amount of this correction depends upon the distance of the object as well as upon the altitude. The parallax is never a large correction, except for the moon. For the sun it is always less than 9″. The amount of this correction for different altitudes will be found in Table 16, Bowditch. It is always added to the observed altitude.

Table 20B, Bowditch, gives the combined corrections for refraction and parallax of the sun. This, of course, would not be used for observations on any other object than the sun, because the parallax would not correspond.

The semi-diameter of the sun varies from about 15′ 45″ to 16′ 15″. Its value is given in the Nautical Almanac for every ten days. For many purposes it would be sufficient to take the correction as 16′. If we observe the lower limb (edge) of the sun we must add this correction to the measured altitude; if the upper limb is observed the correction must be subtracted.

Example. May 1, observed alt. $\underline{\odot}$ (sun's lower limb) $= 27° 12′ 30″$; I. C., $- 20″$; Ht. of eye, 36 ft.; find the true altitude of the center, *h*. (See page 91.)

The separate corrections may always be looked up in this manner if desired, or if required by an examiner, but it need never be done in practice.

ALL CORRECTIONS COMBINED

Table 46, Bowditch, contains corrections to the sun's altitude for different heights of the observer's eye and for different measured altitudes. This combined cor-

rection includes the corrections for dip, refraction, parallax and semi-diameter, the latter being taken as 16′. In order to make allowance for the small variation in the semi-diameter at different dates a small table is added at the bottom of the page, from which a second correction may be taken out according to the time of the year. This table can be used only when the observation is taken on the **lower** limb of the sun.

In another column to the right of the sun's correction is the star's correction of altitude. This is the same as the first, but with the semi-diameter and parallax corrections omitted. These two corrections are too small to measure in case of an object as far away as a star. Neither of these columns should be used for observations on the moon or on a planet. It will be noticed that this table includes all corrections except the I. C. This, of course, could not be included conveniently in a general table. Combine the I. C. with the correction in Table 46 to get the "Correction to altitude." For all ordinary observations it is unnecessary to look up the separate corrections as has been done heretofore. Careful attention should be given to the + and − signs of the corrections.

The refraction correction is large near the horizon and if the actual temperature and air pressure are very different from those for which the table is computed there may be considerable error due to this cause; furthermore, the dip correction is affected by the variation in refraction on the horizon. For these reasons it is best not to measure an altitude when the object is within 10° of the horizon.

Example. May 1, observed alt. $\underline{\odot}$ (sun's lower limb) = 27° 12′ 30″; I. C., − 20″; Ht. of eye, 36 ft. Find true altitude of center, *h*.

Obs. alt. $\underline{\odot}$	27° 12′ 30″	Tab. 46	+8′ 21″
Corr.	+7′ 53″	Aux. Tab.	− 8″
h.	27° 20′ 23″	I. C.	− 20″
		Corr. to alt.	+7′ 53″

PROBLEMS

1. The alt. $\underline{\odot}$ June 21, 1917, was 48° 40′; I. C., − 10″; ht. of eye, 50 ft. What is the true altitude?
Ans. 48° 47′ 55″.

2. Obs'd alt. $\underline{\odot}$ July 1, 41° 10′ 10″; ht. of eye, 26 ft.; I. C., + 1′ 10″. What is the corrected altitude?
Ans. 41° 21′ 06″.

3. Obs'd alt. $\underline{\odot}$ July 30, 61° 41′ 20″; ht. of eye, 48 ft.; I. C., −2′ 00.″ What is the corrected altitude?
Ans. 61° 47′ 51″.

4. Obs'd alt. of Polaris, 43° 10′; ht. of eye, 18 ft.; I. C., 0″. What is the true altitude?
Ans. 43° 04′ 50″.

CHAPTER VIII

LATITUDE

THE latitude of an observer is his distance in degrees north or south of the equator, or, what is the same thing, it is the angular distance from the celestial equator to the point vertically overhead (Zenith). Referring to Fig. 33, it will be seen that the number of degrees in *OQ* on

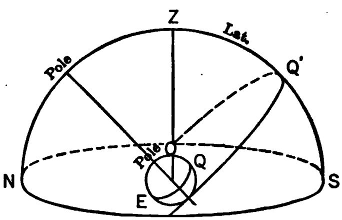


FIG. 33.

the earth equals the number of degrees in *ZQ'* in the sky. *OQ* is the observer's latitude. Notice that Latitude and Declination are measured in just the same way.

LATITUDE BY MERIDIAN ALTITUDE OF THE SUN

The meridian altitude is that taken when the sun bears true north or south. It is nearly the same as the highest altitude which the sun reaches during the day. Unless the vessel is moving rapidly north or south it may

be considered as exactly the same thing. The meridian altitude may be taken when the watch, set accurately to local apparent time, reads twelve o'clock. It is well to begin observing a little before noon, and to notice if the noon altitude is the highest. The altitude should increase by several minutes up to about noon and then begin to decrease. If there is no doubt about the watch

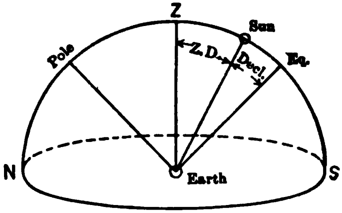


FIG. 34.

being set accurately to noon then the noon altitude may be used and no time wasted in taking other observations, but in case of doubt it is always safe to use the greatest altitude for the meridian altitude.

If the corrected meridian altitude is subtracted from 90° the remainder is the true meridian zenith distance (*Z* to Sun, Fig. 34). If the corrected declination (Eq. to Sun, Fig. 34) is added to, or subtracted from, the meridian zenith distance the result is the latitude, or angular distance of the observer from the equator. If the sun bears south, mark the true zenith distance (Z. D.) North. If the sun bears north, mark the zenith distance South. If the declination is + mark it North; if it is – mark it

LATITUDE BY MERIDIAN ALTITUDE

Obs. alt. $\odot$	$67^\circ 48'$
Corr.	$+11' 34''$
h	$67^\circ 59' 34''$
90°	$89^\circ 59' 60''$
Z	$22^\circ 00' 26''$ N
D	$22^\circ 43' 11''$ N
Lat.	$44^\circ 43' 37''$ N

Table 46	$+ 9' 34''$
I. C.	$+ 2' 00''$
Corr.	$+11' 34''$

Decl. at 4^h	$= +22^\circ 43'.0$
Corr.	$.18$
Dec.	$+22^\circ 43'.18$
	$= 22^\circ 43' 11''$
H. D.	$0'.3$
G. T.	$0^h.6$
Corr.	$0'.18$
	$= 11''$
Long.	$4^h 29^m 48^s$
Eq. t.	$= -4 \quad 17$
G. M. T.	$= 4^h 34^m 05^s$
	$= 4^h.6$

South. It will be + in summer and − in winter, in the northern hemisphere. Then add the Z. D. and Decl. if they are of the same name (both North, or both South); take the difference, if they are of different names, and mark the result with the name of the greater.

Example. Observed meridian altitude of ☉ July 6, 1917 = 67° 48′, bearing South. Height of eye, 36 ft. Index Correction, +2′ 00″. Long., 67° 27′ W. Required the latitude. (See p. 97 for the solution.)

LATITUDE BY THE USE OF A "LATITUDE CONSTANT"

Suppose that we know beforehand, either from the dead reckoning or from having measured an altitude a little before noon, that the noon altitude will be about 67° 48′. We may then take out the correction to the altitude beforehand, find the I. C., and then complete the calculation, all but subtracting the observed altitude. We could then proceed as follows:

First, calculate the so-called "latitude constant" which is 90° − correction + declination (when the Lat. and Decl. are of same name).

	90°	
Corr.	(−)	+11′ 34″
	89°	48′ 26″
Decl.	+22°	43′ 11″
Const.	112°	31′ 37″

Then from this constant subtract the observed altitude as soon as it is measured.

Const.	112° 31′ 37″
Obs. Alt. ⊙	67° 48′
Lat.	44° 43′ 37″ N

This constant is different for different altitudes and for different dates. It must be figured separately for each observation, and so is not really a constant. The advantage of this method is that the latitude is known almost as soon as the sextant is read.

If the Decl. is of opposite name to the Lat. the Decl. must be subtracted. If the Lat. and Decl. are of the same name, but the Decl. is the greater, subtract the Decl.

EXAMPLES

1. Lat., 30° S; Decl., 10° N; corr., + 9′. Lat. const. is 79° 51′.

2. Lat., 10° N; Decl., 20° N; corr., + 10′. Lat. const. is 69° 50′.

THE OLD 89° 48′ RULE

Formerly many navigators obtained latitude by considering that the "correction to altitude" was always the same and equal to 12′. This gave 89° 48′ for a constant. To this they added the declination and then subtracted the altitude corrected for I. C. Applied to the preceding case this rule would give

Const.	89° 48′		Alt. ⊙	67° 48′
Decl.	22° 43′ 11″		I. C.	+2′
	112° 31′ 11″		Alt. ⊙	67° 50′
Alt.	67° 50′			
Lat.	44° 41′ 11″			

Although the result is only about 2′ in error, this method is evidently wrong, because it makes no allowance for the change in dip at different heights or the change in refraction at different altitudes. In some cases the latitude might be as much as 6′ to 8′ in error. Results worked by this rule on examinations are not accepted by the Local Inspectors.

LATITUDE BY EX-MERIDIAN OBSERVATION

Sometimes it is impossible to get the altitude exactly at the instant of noon, on account of clouds; or the navigator may wish to know the latitude a little before the instant of noon. In this case take the altitude within a few minutes of noon, note the exact time of the sight, and proceed as follows:

Change the G. M. T. into L. A. T. by applying the Equation of time and the longitude; then from Table 26, Bowditch, with the Lat. and Decl., take out the change in the sun's altitude in one minute of time; with this number and the number of minutes interval from noon (L. A. T., or 24^h minus L. A. T.) enter Table 27 and take out the correction to the altitude. This correction represents the amount by which the actual altitude is less than the meridian altitude. Adding this correction makes the

LATITUDE BY EX-MERIDIAN

Alt. $\odot$	66° 21′ 00″	Tab. 46	+9′ 31″	Chro.	$4^h\ 51^m\ 58^s$
	+ 9′ 41″	I. C.	+ 10″	C. C.	− 1 30
h	66° 30′ 41″	Corr.	+9′ 41″	G. M. T.	$4^h\ 50^m\ 28^s$
at^2	19 51			Eq. t.	5 43
H	66° 50′ 32″	Tab. 26,	a = 3.3″	G. A. T.	$4^h\ 44^m\ 45^s$
Z	23° 09′ 28″ N	Tab. 27	3″, 18′ 03″	Lo.	4 25 58
D	21° 33′ 29″ N		0.3″, 1 48	L. A. T.	$0^h\ 18^m\ 57^s$
Lat.	44° 42′ 57″ N	at^2	19′ 51″		

Decl. 4^h	+21° 33′.8
corr.	.32
	+21° 33′.48
=	+21° 33′29″

H. D.	0′.4
G. T.	0 .8
Corr.	0′.32

observed altitude equal to the meridian altitude and the rest of the computation is the same as that already described for the meridian observation.

In using Table 26 the Lat. must be known approximately; the D. R. Lat. may be used, or if necessary, the ex-meridian may be worked out first as a meridian altitude to get a latitude sufficiently close for this purpose.

Example. July 15, 1917, obs. alt. ☉ 66° 21′ 00″, bearing South; chro., $4^h\ 51^m\ 58^s$; chronometer correction, $1^m\ 30^s$, fast; I. C., + 10″; Ht. of eye, 36 ft., Lat. by D. R., 44° 50′ N; Long., 66° 27′ W. (See p. 101.)

EXPLANATION (p. 101)

The L. A. T. is found by subtracting the west Longitude in hours from the G. M. T. If the Longitude is East, add it to the G. M. T. If the L. A. T. had been a little before noon, say $23^h\ 40^m$, we should enter Table 27 with 24^h − L. A. T., or 20^m. Notice that the correction is taken out by parts, that is, the 3″ and the 0″.3 are looked up separately and the results added.

LATITUDE BY THE $\phi'\ \phi''$ SIGHT

When the sun is more than 26^m from the meridian the ex-meridian method should not ordinarily be used. If the sun's hour angle is less than 3^h (or 45°) from the meridian, or its bearing not more than 45° from the meridian, the latitude may be found by the following rule:

1. From the chronometer time of the sight find the L. A. T. and thence the hour angle of the sun, *t*. (The hour angle, *t*, is simply the L. A. T. or 24^h minus the L. A. T., turned into degrees.)

2. Add the log tan (*D*) Decl. and log sec. (*t*), hour angle.

3. This sum is the log tan of a new angle ϕ'', which is to be found in Table 44.

4. Add together log sin *h*, log sin ϕ'', and log cosec (*D*) Decl.

5. This sum is the log cos of an angle ϕ', which is to be found in Table 44.

6. The latitude is sum or difference of ϕ' and ϕ''.

7. Mark ϕ'' N. or S. according as declination is N. or S. Mark ϕ' N. if sun bears S., but S. if sun bears N. Then if ϕ' and ϕ'' are of same name, add; if of different names, subtract; give the result the name of the greater.

If the hour angle is more than 3^h, or if the bearing of the sun is greater than 45°, or if the declination of the sun is less than 3°, the result obtained by this method is not satisfactory.

Example. On July 15, 1917, in Lat. 44° 44′ N., Long. 66° 28′ W, by D. R., the observed altitude ☉ was 62° 45′ 40″; watch time, $1^h\ 05^m\ 00^s$ P.M.; I. C., + 20″, off the arc; ht. of eye, 36 ft. Comparison: chro. $6^h\ 38^m\ 00^s$; watch, $2^h\ 02^m\ 10^s$ C. C., − $1^m\ 30^s$. (See p. 104.)

LATITUDE BY $\phi' \phi''$ SIGHT

Watch	$1^h\ 05^m\ 00^s$
C − W	+4 35 50
Chro.	$5^h\ 40^m\ 50^s$
C. C.	− 1 30
G. M. T.	$5^h\ 39^m\ 20^s$
Eq. t.	− 5 43
G. A. T.	$5^h\ 33^m\ 37^s$
Lo.	4 25 52
L. A. T.	$1^h\ 07^m\ 45^s$
t =	16° 56′ 15″

Obs. alt.	62° 45′ 40″
Corr.	+ 9 47
h	62° 55′ 27″
Tab. 46	+9′ 40″
	−13″
	+9′ 27″
I. C.	+ 20
Corr.	+9′ 47″

Dec. 6^h	+21° 33′.0
Corr.	.1
Dec.	+21° 33′.1
H. D.	0.4
G. M. T.	.25
Corr.	0.1
Eq. t. 6^h	$-5^m\ 43^s.1$
Corr.	0 .1
	$-5^m\ 43^s.2$
H. D.	0.3
G. M. T.	.25
Corr.	0.1

t =	16° 56′ 15″	l. sec	0.01926		
D = +	21 33 06	l. tan	9.59655	l. csc	0.43493
h =	62 55 27			l. sin	9.94959
ϕ'' =	22 26 03 N	l. tan	9.61581	l. sin	9.58164
ϕ' =	22 19 35 N			l. cos	9.96616
Lat. =	44° 45′ 38″ N				

EXPLANATION (p. 104)

The arrangement of the angles and logarithms makes it unnecessary to write any angles twice. *D* and ϕ'' both require two logarithms and these are both written on the same line as the angle itself.

In taking out the logarithms of secants, cosecants, tangents, sines or cosines from Table 44 remember that in all cases if the degrees are at the top of the page the names are at the top; if the degrees are at the bottom the names are at the bottom. If the degrees are on the left of the page the minutes (in column marked *M*) are at the left; if the degrees are on the right the minutes are at the right. In all cases the seconds are in the left-hand (minute) column and the correction is in the "Diff." column next to the column from which you take the logarithm. Whether the correction for seconds is added or subtracted may be determined by examining the logarithms to see whether they are increasing or decreasing. Notice that on the first 5 pages of Table 44 the difference columns are marked "Diff. 1′." These are not to be used in the same way as the columns marked "Diff." To obtain the correction divide the "Diff. 1′" by 60 and multiply by the number of seconds. Whenever there is a 10 before the decimal point it may be omitted when writing down the logarithm.

LATITUDE BY MERIDIAN ALTITUDE OF A STAR

Observations on the stars are more difficult than observation on the sun. It is important that the mirrors of the sextant be newly silvered and in good

condition. The best time to observe is at twilight or on moonlight nights, because the horizon can be more distinctly seen at these times.

The observation for latitude by meridian altitude of a star is made by taking the highest altitude, but it is convenient to know beforehand the time when the star will cross the meridian. The calculation of the latitude is the same as for the sun except that the correction for altitude is taken from Table 46 from the column marked "star's correction" and is always subtracted. The declination of the star may be taken from the N. A. in the table of Apparent Places of Stars.

Example. Obs. alt. *α Scorpii* Aug. 1, 1917, 19° 05′ 00″; ht. of eye, 18 ft.; I. C., + 30″. From the N. A. the star is found to pass the meridian at $7^h 45^m$; the Decl. is − 26° 15′.1. Find the latitude.

Obs. alt.	19° 05′ 00″	Tab. 46	−6′ 57″
Corr. to alt.	−6′ 27″	I. C.	+30
h	18° 58′ 33″	Corr. to alt.	−6′ 27″
Z	71 01 27 N		
D	−26 15 06 S		
Lat.	44° 46′ 21″ N		

Stars suitable for meridian observations may be selected by consulting the table in the N. A. headed "Meridian Transit of Stars, 19—". For instance, if it is 7^h P.M. local time Aug. 1, the D. R. Lat. is 44° 55′ N, and you wish to observe for latitude, look in the table and you will find that *δ Scorpii* transits at $7^h 16^m$, *α Scorpii* at $7^h 45^m$ and *α Tri. Aust.* at $8^h 01^m$. Referring to the table of "Apparent Places of Stars," or to the star chart

at the back of the N. A. you will find that *α Tri. Aust.* is too far south to be visible, its declination being 68° S. Either *δ* or *α Scorpii* might be used, but the latter is brighter (that is, its magnitude is a smaller number, 1.2) so use *α Scorpii*.

To find the exact time of transit, or meridian passage, take from the table the time of transit of the star for the first day of the month. Then subtract from this time the correction given on the next page for the day of the month to reduce the time to the date of the observation.

The time of meridian passage may also be found by subtracting the corrected Rt. Asc. of the mean sun from the Rt. Asc. of the star.

When taking the altitude the star may be more easily found by setting the sextant to read the approximate meridian altitude of the star. This will bring the star's image somewhere in the field of view so that it may be more quickly found. The approximate altitude may be computed by first subtracting the latitude from 90° to obtain the Colatitude and then adding the declination if in the same hemisphere as the observer, subtracting if in the opposite hemisphere.

For example, in Lat. (by D. R.) 44° 50′ N, Decl. *α Scorpii*, − 26° 15′ (S.), find the approximate altitude.

Lat.	44° 50′
Co-lat.	45° 10′ (N)
Decl.	−26° 15′ (S)
Approx. alt.	18° 55′

LATITUDE BY ALTITUDE OF THE MOON

The time at which the moon will pass the meridian may be taken from the N. A. for the instant of transit over Greenwich, and corrected for longitude. A convenient way to make this correction is to use the table of proportional parts in the N. A. (Table IV, N. A. for 1917). For example, suppose we wish to find the time of transit of the moon over the meridian $67° 22'$ W. (= $4^h 29^m 28^s$ W.) on July 29, 1917. From the N. A. the G. M. T. of transit is $7^h 50^m$, the difference for one day being 59^m (increasing). If we look in Table IV under 60^m and on line of $4^h 24^m$ (the nearest in the Table) we find the correction to be 11^m. It must be kept in mind that the dates and times in the N. A. are always Astronomical. The same correction may be found in Bowditch, Table 11. The G. M. T. of the moon's transit over the meridian of the observer is found as follows:

G. M. T. of Greenwich Transit	$7^h 50^m$
Corr. for Long.	11
	$8^h 01^m$
Long.	4 29
G. M. T. of Local Transit	$12^h 30^m$

The observation should be begun a little before the chronometer indicates $12^h 30^m$. It will be necessary to observe the upper or the lower limb of the moon, according to which is visible. It is only at or near the time of full moon that both could be observed. This observed altitude is corrected by means of Table 49, Bowditch. The table gives the correction for a height of eye of 35 ft. For other heights a further correction is taken from

a little table following the table of corrections to the altitude. The declination and the horizontal parallax (H. P.) may be taken from the N. A. in the table headed "Moon, 19—." When correcting the declination of the moon use Table IV, N. A. (proportional parts) to save multiplication, the time interval being found in the left column and the variation in the declination at the top of the page. After the altitude and the declination have been corrected, the rest of the calculation is the same as for a sun observation.

It is important that the G. M. T. be known accurately and that all the small corrections be carefully attended to, because small errors in the data produce larger errors in the results for moon observations than for sun or star observations.

Example. Meridian alt. moon's upper limb July 29, 1917, was 20° 07′ 00″, bearing South. L. M. T., $8^h\ 01^m$. Longitude, 67° 22′ W. Ht. of eye, 12 feet. I. C., + 10″.

Obs. alt.	20° 07′ 00″	Table 49	
Corr. to alt.	+32 54	(H. P. 58′.2)	+30′ 20″
h	20° 39′ 54″	Corr. 12 ft.	+ 2 24
Z	69° 20′ 06″ N		+32′ 44″
D	−24° 33′ 30″ S	I. C.	+ 10″
Lat.	44° 46′ 36″ N	Corr. to alt.	+32′ 54″

L. M. T.	$8^h\ 01^m$	Decl. 12^h	−24° 32′.3
Lo.	4 29	Corr. Tab. IV	1 .2
G. M. T.	$12^h\ 30^m$	Corr. Decl.	−24° 33′.5

NOTE. — The correction for the declination is taken from Table IV, N. A., for a diff. of 50 and interval of 30^m, which gives 12. Since the difference is really 5′.0 the correction is 1′.2, or one-tenth of the number in the table.

LATITUDE BY THE ALTITUDE OF A PLANET

The latitude is found from the meridian altitude of a planet in just the same way as for a star, except that the declination must be corrected. The declination changes slowly, so it is given in the Almanac for the instant of Greenwich Mean Noon each day.

LATITUDE BY ALTITUDE OF THE POLE STAR (POLARIS)

The altitude of the pole star may be taken at any time and the chronometer time noted. The latitude is calculated as follows:

Change the G. M. T. into Greenwich Sidereal Time by adding the G. M. T., the Rt. Asc. of the Mean Sun, and the correction at the foot of the same page, (N. A.) for the hours and minutes of the G. M. T. Subtract the W. longitude and the result is Local Sidereal Time. Then look in Table 1, N. A., for the correction to the altitude of Polaris. This correction is to be applied in addition to the usual correction from Table 46 for dip and refraction.

Example. Obs. Alt. of *Polaris*, Aug. 1, 1917, at Chro. T. $13^h\ 01^m\ 30^s$, was $44°\ 14'\ 00''$; C. C., $-\ 0^m\ 30^s$; ht. of eye, 30 feet; Long. $67°\ 22'$ W.

LATITUDE BY THE POLE STAR

Chro.	$13^h\ 01^m\ 30^s$	Obs. alt.	$44^\circ\ 14'\ 00''$
C. C.	-30^s	Corr. Tab. 46 (Bowditch)	$-6'\ 20''$
G. T.	$13^h\ 01^m\ 00^s$		$44^\circ\ 07'\ 40''$
Rt. Asc. Mean Sun	8 38 05	Corr. Tab. I. (N. A.)	$+39'\ 06''$
Corr.	2 08	Lat.	$44^\circ\ 46'\ 46''$ N
G. S. T.	$21^h\ 41^m\ 13^s$		
Lo.	4 29 28		
L. S. T.	$17^h\ 11^m\ 45^s$		

A ϕ' ϕ'' SIGHT BY A STAR

In this case it is necessary to find the hour-angle of the star. After finding this, the rest of the computation is the same as for a ϕ' ϕ'' sight on the sun.

To find the hour-angle of the star, add to the G. M. T. the Right Ascension of the Mean Sun (R. A. M. S.) and the reduction (Red.) for the number of hours in the G. M. T. These are found on the same page in the Nautical Almanac.* This sum is the Greenwich Sidereal Time (G. S. T.). Subtracting from this the star's Right Ascension we have the hour-angle (H. A.) of the star at Greenwich. Taking the difference between the H. A. at Greenwich and the West Longitude of the ship, we have the H. A. of the star at the ship. In East Longitude, add the Long. to the H. A. at Greenwich. This H. A., turned into degrees, is *t*, for which we take out the secant.

The R. A. and Decl. of the star will be found in the N. A. in a Table marked "Apparent Places of Stars, 19—."

Example. Aug. 27, 1917, P.M., in Lat. 44° 47′ N, Long. 66° 22′ W; the observed alt. of *Antares* (*α Scorpii*) is 16° 34′, bearing South; watch time, $7^h\ 21^m\ 30^s$; C−W, + $4^h\ 31^m\ 21^s$; C. C., − $1^m\ 40^s$ on G. M. T.; ht. of eye, 17 ft.; I. C., − 20″. Find the latitude.

* The reduction may also be found in Bowditch, Table 9.

$\phi' \phi''$ SIGHT ON A STAR

Watch time	$7^h\ 21^m\ 30^s$	Obs. alt.	$16°\ 34'$	R. A. ★	$16^h\ 24^m\ 22^s.6$
C − W	$+4\ 31\ 21$	Corr.	$-7'\ 36''$	Decl. ★	$-26°\ 15'.1$
Chro. time	$11^h\ 52^m\ 51^s$	h	$16°\ 26'\ 24''$		
C. C.	$-1\ 40$				
G. M. T.	$11^h\ 51^m\ 11^s$	Table 46	$-7'\ 16''$		
R. A. M. S.	$10\ 20\ 35.9$	I. C.	$-20''$		
Red.	$1\ 57.0$	Corr.	$-7'\ 36''$		
G. S. T.	$22^h\ 13^m\ 43^s.9$				
R. A. ★	$16\ 24\ 22.6$				
H. A. from Gr.	$5^h\ 49^m\ 21^s.3$				
Lo.	$4\ 25\ 28.0$				
H. A.	$1^h\ 23^m\ 53^s.3$				
t	$20°\ 58'\ 20''$				
t	$20°\ 58'\ 20''$	sec	0.02977		
D	$-26\ 15\ 06$	tan	9.69301	csc	0.35426
h	$16\ 26\ 24$			sin	9.45180
ϕ''	$27\ 50\ 31$ S	tan	9.72278	sin	9.66935
ϕ'	$72\ 36\ 48$ N			cos	9.47541
Lat.	$44°\ 46'\ 17''$ N				

PROBLEMS

1. On July 5, 1917, the merid. alt. ☉ was 70° 10′ bearing South; I. C., − 2′ 00″; ht. of eye, 36 ft.; Declination, + 22° 48′ 42″. Find the latitude.

Ans. 42° 31′ 07″.

2. A vessel in Lat. 39° 01′ N, Long. 56° 10′ W (by D. R.), sails S 63° W (by compass) 90 miles, to noon (var. 19° W, dev. 6° E). At noon, Aug. 10, 1917, the alt. ☉ was 67° 32′ (South); ht. of eye, 36 ft.; I. C., + 1′ 00″; chro. time, 3^h 50^m. Decl. at 4^h, + 15° 37.3′; H. D., 0′.7; Equa. of time, − 5^m $14^s.0$; H. D., $0^s.4$. What is the error in the D. R. Lat.? *Ans.* 8.′2 too far N.

3. Obs. merid. alt. ☉, 18° 10′, bearing N; ht. of eye 26 feet; I. C., + 1′ 00″; G. M. T., 2^h 30^m, June 25, 1917. Decl. at 2^h, + 23° 24.′4; H. D. 0′.1 (decr.). Find the latitude. *Ans.* 48° 16′.6, South.

4. On July 26, 1917, obs. alt. ☉ was 64° 18′, bearing S; I. C., + 15″; ht. of eye, 8 ft.; watch, 11^h 50^m 30^s; C − W, − 6^h 58^m 58^s; C. C., − 1^m 27^s; Long. 4^h 25^m 26^s; Decl. + 19° 28′ 30″. Equa. of time, 6^m 20^s (subtr. from mean time). Find the latitude (by ex-meridian).

5. Corrected alt. of sun, 15° 22′ 42″, bearing S and E; corrected Decl., − 21° 15′ 40″; G. M. T., 1^h 43^m 05^s (P.M.); Long. 4^h 44^m 18^s W; Equa. of time, 12^m 03^s (add to mean time). Find the latitude by $\phi'\phi''$ method.

Ans. 42° 21′.1 N.

6. On Jan. 28, 1910, in Lat. 42° 25′, Long. 70° 04′, the observed alt. ☉ is 28° 30′ 00″, bearing South and East;

chronometer time, $4^h\ 16^m\ 19^s$ P.M. C. C., $+ 1^m\ 19^s$; ht. of eye, 30 ft.; I. C., $+ 10''$ (off the arc); Equa. of time $- 13^m\ 03^s$; corrected Decl., $- 18°\ 18'\ 20''$. Find the latitude. *Ans.* Lat. $42°\ 28'\ 56''$ N.

7. Observed meridian alt. *Antares*, $21°\ 30'\ 30''$ (S); ht. of eye, 26 ft.; I. C., $+ 30''$; Decl., $- 26°\ 15'.1$. Find the latitude. *Ans.* $42°\ 21'\ 21''$ N.

8. Obs. alt. *Polaris* Sept. 22 (P.M.), 1917, $40°\ 17'$; G. M. T., $1^h\ 19^m\ 00^s$; ht. of eye, 30 ft.; I. C., $0''$; Long., $61°\ 00'$ W. Find the latitude. The R. A. M. S. is $12^h\ 03^m\ 06^s$; reduction, $2^m\ 11^s$; corr. (Table I, N. A.), $- 0°\ 30'.8$. *Ans.* $39°\ 39'.7$ N.

9. Obs. alt. $\underline{\odot}$, $69°\ 21'\ 30''$, bearing N; I. C., $- 1'\ 10''$; ht. of eye, 18 ft.; Decl. $+ 9°\ 00'\ 26''$. Find the latitude.

10. Obs. alt. $\underline{\odot}$ Jan. 20, 1910, $20°\ 05'$; I. C., $0''$; G. A. T., $1^h\ 35^m\ 28^s$; Lat. by D. R., $49°\ 20'$ N; Long. by D. R., $1^h\ 05^m\ 20^s$ W; ht. of eye, 16 ft.; Decl. at G. M. N., $- 20°\ 15'.0$; H. D., $0'.5$. Find the latitude.

11. Work prob. 2, p. 127, backwards; that is, assume the longitude to be that given in the answer and obtain the latitude by the $\phi'\phi''$ method.

CHAPTER IX

LONGITUDE

THE longitude of a place east or west of Greenwich is the number of degrees on the equator between the meridians of the two places, or, it is the angle at the pole between these two meridians. Since there is a fixed relation between the number of hours and the number of degrees in a circle, longitude may be expressed in either of these units. The determination of longitude depends upon determining the time at the ship and the time at Greenwich at the same instant. In Figs. 35 and 36 the Greenwich time is 9^h and the time at the ship is 6^h. The difference (3^h) is the west longitude of the ship, expressed in hours.

The method most commonly used for determining longitude is that known as the "time sight" or "chronometer sight." This consists in measuring the altitude of the sun or a star when it bears nearly east or west from the observer, and then calculating the Local Apparent Time. The difference between this Local Apparent Time and the Greenwich Apparent Time is the longitude of the ship. The Greenwich Apparent Time may be found from the chronometer.

The Local Apparent Time, or hour angle of the sun, is found by solving a spherical triangle, the necessary data being (1) the corrected altitude, h, (2) the polar distance

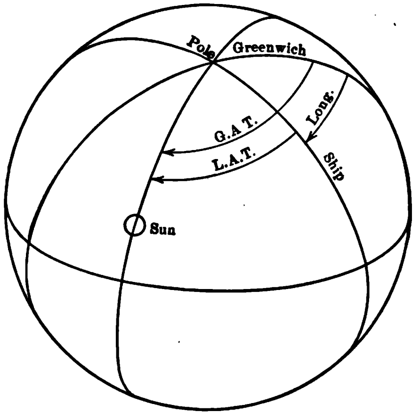

Pole
Greenwich
G.A.T.
L.A.T.
Long.
Ship
Sun

FIG. 35.

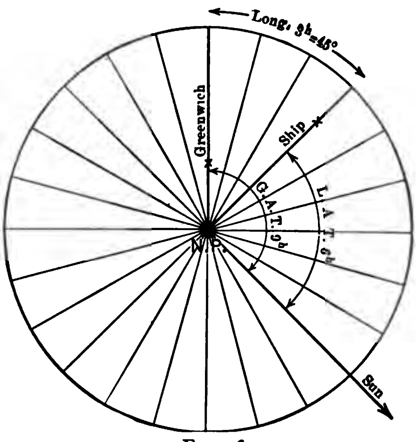

Long. 3h=45°
Greenwich
Ship
G.A.T. 9h
L.A.T. 6h
N.P.
Sun

FIG. 36.

of the sun, which, for north latitudes, is 90° minus the N. declination, or 90° plus the S declination, and (3) the latitude of the ship, usually the latitude by D. R. (For south latitudes, the polar dist. is found by adding the N declination or subtracting the S declination.)

TAKING THE ALTITUDE

In measuring the altitude it is advisable, in order to increase the accuracy, to measure three altitudes in succession and to use the average, instead of taking only one altitude. Each time an altitude is taken the hours, minutes and seconds on the observing watch should be noted. After a little experience the observer will find that he can take altitudes as often as once per minute without difficulty. A convenient way is to set the index on a line of the arc, say 29° 10′, and watch the sun's image until the lower limb is in contact with the horizon. At this instant he notes the time. He then sets the index on the next line, the 29° 20′ line if the sun is rising, and waits for the next contact. Three such observations will usually be sufficient. In taking the sights he may need an assistant to read the watch; in this case he calls out "Stand by" when the sun's lower limb is nearly on the horizon, and "Time" or "Mark" when the contact is perfect. The index correction should be determined immediately after (or before) the sight. The observing watch should be compared with the chronometer.

FINDING THE GREENWICH APPARENT TIME

Take the average of the observed watch times and add the C − W to get the chronometer time of the sight. Then add or subtract the C. C. to get true G. M. T. Finally add or subtract the corrected Equation of time to get Greenwich Apparent Time (G. A. T.). If this G. A. T. is in Civil Time it should be changed into Astronomical Time.

SOLVING THE TRIANGLE

Add together the corrected alt. (h), the Latitude by D. R. (L) and the polar distance (p). Divide this sum by 2 and from the "half sum" (s) subtract the altitude, giving the "remainder" ($s - h$). Then take from Table 44 the following logarithms and add them together; the secant of the Latitude, the cosecant of the polar dist., the cosine of the "half sum" and the sine of the "remainder."

(See "Explanation," p. 105, for use of Table 44.) If p is greater than 90°, take the minutes from the left-hand column, on the same side of the page as the degrees. The characteristic, or index, of the logarithm will usually be 10 for the secant and the cosecant, and may be omitted. The characteristic for the cosine and sine will usually be 9, and must be kept. The characteristic for the sum of the four logs will usually be 18 or 19.

To find the local apparent time (L. A. T.) we may proceed in two different ways. The first is to

divide this sum (of the 4 logs) by 2, and look for the result in the sine column in Table 44. The hours, minutes and seconds may be taken from columns to the left, the A. M. column being used if the observation is made in the forenoon, otherwise the P.M. column.

To find the exact number of seconds take the difference between your log sine and the nearest log sine found in the table; look for this difference in the small table at the foot of the page, on the line marked *A* if you are using an *A* column or on line of *C* if using a *C* column; above this number is the number of seconds of time to be added to or subtracted from the number of *h. m. s.* corresponding to the log sine found in the table. The L. A. T. should be expressed in Astronomical Time.

The second way of finding the L. A. T. is to

look in Table 45 for the sum of the four logs (do not divide by 2). The logs (haversines) in this table are given for every second of time so it will be sufficient to take the nearest one in the table; the characteristic of the sum, if 19, must be called 9; if 18, it must be called 8. The hours and minutes of the L. A. T. will be at the top of the page and the seconds on the left side, if the time is P.M. If the time is A.M. the hours and minutes are at the bottom and the seconds at the right.

This second method has four advantages. (1) It is not necessary to divide by 2; (2) it is not necessary to correct for seconds; (3) the A.M. time is already expressed in astronomical time; (4) the hours, minutes and

seconds of the longitude may be quickly converted into degrees, minutes and seconds by the same table, already open.

After the L. A. T. is found take the difference between the L. A. T. and the G. A. T. This is the longitude in hours, minutes and seconds, which must be converted into degrees, minutes and seconds. If the Greenwich time is later than the ship's time the longitude is west; otherwise it is east.* The L. A. T. and G. A. T. should both be expressed as astronomical time before subtracting.

Example 1. July 8, 1917, P.M., observed the alt. ☉ as follows: alt. 33° 25′ 00″, watch $4^h\ 11^m\ 33^s$; alt. 33° 36′ 00″, watch $4^h\ 12^m\ 32^s$, alt. 33° 46′ 00″, watch $4^h\ 13^m\ 28^s$. Ht. of eye, 36 ft., I. C., 0″; C. C., $-\ 08^s$. Comparison: chro. $8^h\ 40^m 00^s$, watch, $4^h\ 05^m\ 08^s$. Lat. by D. R. 44° 43′ 15″. (See p. 122.)

In looking up the L. A. T. we find in the table, opposite $4^h\ 16^m\ 32^s$, the log sine 9.72502. This is 8 less than the given log. In the auxiliary table, line *A*, we find 8 and above it 3^s. The L. A. T. is therefore $4^h\ 16^m\ 35^s$.

By the second method we look up 9.45020 (log hav) in Table 45 and obtain $4^h\ 16^m\ 35^s$ at once. To change the longitude $4^h\ 25^m\ 51^s$ into degrees we find $4^h\ 25^m$ at the top of the next page and beside it 66° 15 ; in the side column opposite 48^s we find 12′; the odd 3^s = 45″.

* "Greenwich time least, longitude east; Greenwich time best, longitude west."

	$4^h\ 11^m\ 33^s$
	$4\ \ 12\ \ 32$
	$4\ \ 13\ \ 28$
Mean	$4^h\ 12^m\ 31^s$
C – W	$+4\ \ 34\ \ 52$
Chro.	$8^h\ 47^m\ 23^s$
C. C.	-08
G. M. T.	$8^h\ 47^m\ 15^s$
Eq. t.	$-4\ \ 49$
G. A. T.	$8^h\ 42^m\ 26^s$
h	$33°\ 44'\ 13''$
L	$44\ \ 43\ \ 15$
p	$67\ \ 31\ \ 00$
	$2)\overline{145°\ 58'\ 28''}$
s	$72°\ 59'\ 14''$
rem.	$39°\ 15'\ 01''$

	$33°\ 25'\ 00''$
	$33\ \ 36\ \ 00$
	$33\ \ 46\ \ 00$
Mean	$33°\ 35'\ 40''$
Corr.	$+8\ \ 33$
h	$33°\ 44'\ 13''$
Tab. 46	$+8'\ 47''$
	-14
Corr. to alt.	$+8'\ 33''$
sec	0.14841
csc	0.03433
cos	9.46626
sin	9.80120
	$2)\overline{19.45020}$
sin $\frac{1}{2}t$	9.72510
L. A. T.	$4^h\ 16^m\ 35^s$
G. A. T.	$8\ \ 42\ \ 26$
Long.	$\left.\begin{array}{l} 4^h\ 25^m\ 51^s \\ =66°\ 27'\ 45'' \end{array}\right\}$ W

Decl. 8^h,	$+22°\ 29'.2$
Corr.	$.2$
	$+22°\ 29'.0$
	$=22°\ 29'\ 00''$
H. D.	0.3
G. T.	0.7
Corr.	0.21
$p =$	$67°\ 31'\ 00''$
Eq. t. 8^h,	$4^m\ 48^s.8$
	$.3$
Eq. t.	$-4^m\ 49^s.1$
H. D.	0.4
G. T.	0.7
Corr.	0.28

Watch	$7^h\ 40^m\ 34^s$	Alt. ⊙	$33°\ 01'\ 20''$	Decl. 0^h,	$+21°\ 35'.3$
C – W	$7\ \ 24\ \ 08$		$+8\ \ 31$	Corr.	$.1$
Chro.	$0^h\ 16^m\ 26^s$	h	$33°\ 09'\ 51''$	Decl.	$+21°\ 35'.2$
C. C.	$-1\ \ 30$				$=21°\ 35'\ 12''$ N
G. M. T.	$0^h\ 14^m\ 56^s$	Tab. 46	$+8'\ 45''$	H. D.	0.4
Eq. t.	$-5\ \ 42$		-14	G. T.	0.3
G. A. T.	$0^h\ 09^m\ 14^s$ July 15	Corr.	$+8'\ 31''$	Corr.	0.12

$p = 68°\ 24'\ 48''$

h	$33°\ 09'\ 51''$			Eq. t. 0^h,	$-5^m\ 41^s.5$
L	$44\ \ 40\ \ 00$	sec	.14800		$.1$
p	$68\ \ 24\ \ 48$	csc	.03158	Eq. t.	$-5^m\ 41^s.6$
	$146°\ 14'\ 39''$				
s	$73°\ 07'\ 20''$	cos	9.46289	H. D.	0.3
rem.	$39°\ 57'\ 29''$	sin	9.80769	G. T.	0.3
			19.45016	Corr.	0.09

Tab. 45, L. A. T.	$19^h\ 43^m\ 26^s$	July 14
G. A. T. $(+24^h)$	$24\ \ 09\ \ 14$	July 14
Long.	$4^h\ 25^m\ 48^s$	
	$=66°\ 27'$ W (Table 45)	

Example 2. July 15, 1917, A.M., observed alt. $\underline{\odot}$, $33° 01' 20''$; watch, $7^h 40^m 34^s$; ht. of eye, 36 ft.; I. C., $0''$. Comparison: chro., $0^h 26^m 00^s$ P.M.; watch, $7^h 50^m 08^s$ A.M.; C. C., $- 1^m 30^s$; Lat. by D. R., $44° 40'$ N. (See p. 123.) Notice that 24^h is added to the G. A. T. before subtracting the L. A. T.

TIME-SIGHT BY A STAR

When finding longitude by a chronometer sight of a star the only change is that, instead of comparing the apparent solar times, the hour angle (H. A.) from Greenwich is compared with the hour angle at the ship. The observation is made in the usual way and the chronometer time obtained as explained before.

To obtain the Greenwich Sidereal Time (G. S. T.) we simply add together the G. M. T., the Right Ascension of the Mean Sun (R. A. M. S.), and the correction at the foot of the page for the hours in the G. M. T.* Subtracting the R. A. of the star we have the H. A. from Greenwich.

If the spherical triangle is solved exactly as for the sun observation the result will be, not the L. A. T., but the local hour angle (H. A.) of the star. The longitude in hours is the difference between the two hour angles.

Example. Aug. 27, 1917, P.M., Lat. $44° 47'$ N. Long. $66° 22'$ W, observed alt. of *Arcturus* (*α Boötis*) West, $38° 45'$; watch time, $7^h 43^m 08^s$; C − W, $+ 4^h 31^m 21^s$; C. C., $- 1^m 40^s$; ht. of eye, 17 ft. I. C., $- 20''$. Find the longitude.

* This correction may also be taken from Bowditch, Table 9.

Watch	$7^h\ 23^m\ 08^s$	Obs. alt. ✱	$38°\ 45'$	R. A. ✱	$14^h\ 11^m\ 54^s.6$
C − W	+4 31 21	Corr.	$-5'\ 32''$	Decl. ✱	$+19°\ 36'.7$
Chro.	11 54 29	h	$38°\ 39'\ 28''$	p	$70°\ 23'.3$
C. C.	−1 40				
G. M. T.	11 52 49	Tab. 46	$-5'\ 16''$		
R. A. M. S.	10 20 35 .9	I. C.	$-20''$		
Red.	1 57 .3	Corr.	$-5'\ 32''$		
G. S. T.	$22^h\ 15^m\ 22^s.2$				
R. A. ✱	14 11 54 .6				
H. A. from Gr.	$8^h\ 03^m\ 27^s.6$				

h	$38°\ 39'\ 28''$		
L	44 47 00	sec	0.14888
p	70 23 18	csc	0.02596
	2)153 49 46		
s	76 54 53	cos	9.35487
$s-h$	38 15 25	sin	9.79183
H. A.	$3^h\ 38^m\ 01^s$	hav	9.32154
Gr. H. A.	8 03 27 .6		
Long.	$4^h\ 25^m\ 26^s.6$		
	$66°\ 21'\ 39''$ W		

WHEN TO OBSERVE FOR LONGITUDE

The principal error in the computed longitude is likely to come from the error in the D. R. Lat. When the sun is exactly east or west this error has no effect. It is worth while, therefore, to make the observation at such times (if it is possible) because there always is an uncertainty about the D. R. Lat. If, however, the sun has an altitude of less than 10° when it is E or W it will be better to observe when the altitude is higher.

To find the L. A. T. when the sun is east or west look in the table of Azimuths of the Sun (H. O. No. 71), on the page marked with the degree of the Lat. and in the column marked with the Decl.; opposite the bearing which is nearest to 90° will be the L. A. T., to the nearest 10^m of time.

If the tables are not at hand, the observation may be made when the compass bearing of the sun shows that it is about true east or west.

CROSSING THE 180° MERIDIAN

When a ship changes her longitude she gains time or loses time according to whether she is traveling west or east. A navigator starting from Europe and sailing for America will have to set his clock back each day in order to have it read the local time of the ship. In traveling around the globe this change in time would amount to 24 hours and would result in the ship's calendar being one day behind at the end of the voyage. To avoid this

discrepancy in dates the change in date is always made when crossing the 180° meridian.

If a vessel is going west the calendar is set one day ahead at the midnight which is nearest the time of crossing the line. This results in one day of the week being omitted from the calendar. If the vessel is going east a day is repeated, there being two Mondays, for example, in the same week.

PROBLEMS

1. Observation for Longitude (P.M.), Aug. 8, 1917. Observed altitudes ☉ 32° 06′ 30″, 31° 16′ 30″, 30° 20′ 10″; watch readings, $3^h\ 36^m\ 32^s$, $3^h\ 41^m\ 00^s$, $3^h\ 46^m\ 18^s$; ht. of eye, 8 ft.; I. C., + 1′ 00″; C. C., − $1^m\ 30^s$. Comparison: Chro. $10^h\ 30^m\ 00^s$; watch $5^h\ 28^m\ 52^s$. Lat. by D. R., 44° 47′ N; Decl. + 16° 08′.3; Equa. of time, − $5^m\ 28^s.8$. Find the longitude.

2. Observed alt. ☉, 57° 37′ 50″; watch, $1^h\ 46^m\ 03^s$; C − W, + $4^h\ 35^m\ 50^s$; ht. of eye, 36 ft.; I. C., + 25″; C.C., − $1^m\ 30^s$; Decl., + 21° 32′.9; Equa. of time, − $5^m\ 43^s$; Lat. by D. R., 44° 43′ 15″. Find the longitude.

Ans. 66° 27′ 45″ W.

3. Obs. alt. ☉, 48° 40′; watch, $8^h\ 53^m\ 01^s$ A.M.; C − W, + $4^h\ 40^m\ 10^s$; C. C., − $0^m\ 01^s$; I. C., − 10″; ht. of eye, 48 ft.; Decl., + 23° 27′.0; Equa. of time, − $1^m\ 26^s.8$; Lat. by D. R., 44° 43′ N. Find the longitude.

4. Corrected alt. ☉, May 19, 1910 (P.M.), 44° 05′; G. M. T., $6^h\ 55^m\ 10^s$; Lat. by D. R., 42° 00′; Decl.,

$+ 19° 42'.1$; Equa. of time, $+ 3^m 43^s.4$. Find the longitude. *Ans.* 56° 56'.5 W.

5. Obs. alt. ☉, 15° 10′ (P.M.); ht. of eye, 25 ft.; I. C., + 1′ 30″; G. M. T., $6^h 51^m 05^s$; Decl., − 21° 29′.4 Equa. of time, $+ 11^m 37^s.6$; Lat. by D. R., 39° 50′ N. Find the longitude.

6. Observed alt. *Jupiter* (East), Jan. 9, 1907, 44° 59′; ht. of eye, 20 ft.; I. C., − 1′ 00″; G. M. T., $12^h 22^m 02^s$; Lat. by D. R., 42° 18′ N; Decl. *Jupiter* at G. M. N., + 23° 18′ 22″; H. D., + 1″; Rt. Asc. *Jupiter* $6^h 19^m 17^s.3$; H. D., $- 1^s.4$, Rt. Asc. Mean Sun, $19^h 11^m 29^s.5$; reduction, $2^m 01^s.9$. Find the longitude.

7. Obs. alt. ☉, 15° 30′ (bearing SE); ht. of eye, 20 ft.; I. C., + 30″; G. M. T., $1^h 33^m 00^s$; Lat. by D. R., 42° 09′ N; Decl., − 21° 15′.7; Equa. of time, $+ 12^m 00^s$. Find the longitude.

CHAPTER X

AZIMUTH

Azimuth Tables

THE compass error is usually found at sea by taking a bearing of the sun with the azimuth sights or by reading the position of the shadow cast by the shadow pin, thus obtaining the compass bearing of the sun; the sun's true bearing is then taken from the Azimuth Tables (either Hydrographic Office Publication No. 71, or Burdwood's Tables) for the Local Apparent Time of the observation. In taking out the sun's bearing you will need to know the latitude of the ship, the sun's declination (or the date), and the Local Apparent Time, or sun's hour angle. To find the L. A. T. you must observe the watch time when you take the compass bearing of the sun. If an observation for longitude has just been made the difference between the computed L. A. T. and the watch reading of the sight will be the error of the watch. This error applied to the watch time of the compass observation will give the true L. A. T. when the sun's bearing is required. The Lat. by D. R. is always sufficiently accurate for looking up the sun's bearing, and the declination may always be found because the G. M. T. is known.

To take out the sun's bearing from the Azimuth Table find the page marked with the degrees of the Latitude, noting whether the Lat. and Decl. are of the same or of contrary names. In the column marked with the degrees of the declination (or the date) and on the line with the Apparent Time will be found the sun's true bearing. This must be marked N if the latitude is North, but S if the latitude is South; and it must be counted toward the East if in the morning, West if in the afternoon.

INTERPOLATING FOR MINUTES

To obtain the bearing more accurately we may allow for the variation due to (1) Latitude, (2) Declination, and (3) the Apparent Time. Suppose that we wish to find the bearing for Lat. 40° 20′ N, Decl. 20° 10′ N, and L. A. T. $4^h\ 04^m$ P.M. Looking in the table for Lat. 40°, Decl. 20° (same name) and for 4^h we find 92° 49′. This must be marked N 92° 49′ W. For the same Decl. and App. Time but for Lat. 41° we find 93° 31′. The change in bearing for a change of 1° of Lat. is therefore 52′, and the change for 20′ is $\frac{20}{60} \times 52'$, or 17′; this must be added to the 92° 49′ because the bearing increases when the latitude increases. To allow for the 10′ of Decl. we find that for 21° Decl. (on the same page) the bearing is 91° 48′. This is 1° 01′ or 61′ less for 1° of Decl. The amount to be subtracted from 92° 49′ for 10′ of Decl. is $\frac{10}{60} \times 61 = 10'$. For L. A. T. $4^h\ 04^m$ the decrease in bearing is found by noting that for $4^h\ 10^m$ the bearing is 91° 10′, a decrease of 1° 39′, or 99′, for 10^m of time. The

correction (to be subtracted) for 4^m is $\frac{4}{10} \times 99' = 40'$. The bearing at $4^h\ 04^m$ for Lat. 40° 20′ N and Decl. 20° 10′ N is $92°\ 49' + 17' - 10' - 40' = 92°\ 16'$. This is marked N 92° 16′ W which is equivalent to S 87° 44′ W. In obtaining the bearing for correcting the compass it will seldom be necessary to work closer than a degree or half-degree.

If a time sight has not been taken, the L. A. T. for taking out the bearing may be found by noting the chronometer time corresponding to the compass bearing. The chronometer time corrected for the C. C., the equation of time, and the longitude is the L. A. T.

Example 1. The computed L. A. T. from a chronometer sight is $9^h\ 25^m\ 18^s$. The watch read $9^h\ 20^m\ 10^s$ at time of sight. At watch time $9^h\ 30^m\ 00^s$ the shadow pin reading is N 11° W. The Lat. is 42° 00′ N; the Decl. is − 22° 47′; find the compass error.

L. A. T.	$9^h\ 25^m\ 18^s$
Watch	9 20 10
Slow	$5^m\ 08^s$
	9 30 00
Loc. App. Time	$9^h\ 35^m\ 08^s$ at compass observation.

Sun's true bearing, by Table	N 145° 20′ E
Comp. bear. of Sun S 11° E, or	N 169° E
Error of Compass	24° 40′ W

The error is W because the true bearing is greater than the compass bearing, or to the left.

Example 2. Chronometer time of compass bearing $1^h\ 22^m\ 38^s$; C. C., -15^s; Equa. of time, $-4^m\ 51^s$; Long.,

$55^\circ 35' 48''$ W; Lat. $42^\circ 00'$ N; Decl., $- 22^\circ 47'$. Shadow reading 349°. Find the compass error.

Chro.	$1^h\ 22^m\ 38^s$	349° shadow
C. C.	-15	180
G. M. T.	$1^h\ 22^m\ 23^s$	169° sun
Eq. t.	$-4\ \ 51$	
G. A. T.	$1^h\ 17^m\ 32^s$	
Long.	$3\ \ 42\ \ 23$ W	
L. A. T.	$9^h\ 35^m\ 09^s$ at compass observation.	

Sun's bearing by Table	$145^\circ\ 20'$
Compass bearing of Sun	169°
Total error of Compass	$24^\circ\ 40'$ W

If the variation is 27° W, the deviation is $2^\circ\ 20'$ E, because the magnetic bearing is to the right, or greater than the compass bearing.

AZIMUTH OF A STAR

In obtaining the true bearing of a star or a planet whose declination is greater than 23°, it will be necessary to use Hydr. Office Publ. No. 120. This table is used in the same way as No. 71 except that instead of being given for hours of the L. A. T. the bearing is given for *hour angles* (H. A.), that is the number of hours either before or after the time of meridian passage.

Example. Lat. 35° N, Decl. of star 30° N. Hour angle of star $4^h\ 10^m$, E. Find the star's true bearing. From H. O. No. 120 the result is found to be $76^\circ\ 47'$. This is to be marked N $76^\circ\ 47'$ E, according to the directions at the foot of the page.

In case the Lat. and Decl. are of different names it is necessary to enter the table with the supplement of the H. A. (180° – H. A.) and to use the supplement of the azimuth which is found in the table.

If the Hour Angle of the star is not known it may be found from the G. M. T. as follows:

Add together the G. M. T., the R. A. M. S., and the reduction. This gives the G. S. T. Subtract from this the R. A. of the star, obtaining the H. A. at Greenwich. Then subtract from this the west longitude, obtaining finally the H. A. of the star at the ship's meridian.

TIME-AZIMUTH, ALTITUDE-AZIMUTH

If the azimuth tables are not at hand the azimuth may be found by solving a spherical triangle, having given the Lat., Decl. and L. A. T.; this is called the "time-azimuth." If the triangle must be solved, however, it is more convenient to measure the sun's altitude with the sextant and to solve the triangle by the following rule, known as the "altitude-azimuth."

Add together the polar dist., the Lat. and the Alt. Divide the sum by 2 and call this the "half sum." Take the difference between the half sum and the polar dist., and call this the "remainder." Then add together the following logarithms; the secant of the Lat., the secant of the alt., the cosine of the half sum, and the cosine of the remainder. The sum of these four logs divided by 2 is the cosine of half of the azimuth. Look up the angle corresponding to the cosine and double it.

Example. Corrected alt. of sun, 15° 23′; Lat. 42° 20′ N; Decl., − 21° 16′; shadow pin, 300°. Find the azimuth.

h	15° 23	sec	0.01585		
L	42 20	sec	0.13121		
p	111 16			shadow	300°
	2)168 59				180
s	84 30	cos	8.98157	sun	120°
$s - p$	26 46	cos	9.95078		
			2)19.07941		
		cos	9.53970		

½ Az.	69° 43′
Azimuth	139° 26′
Compass Azimuth	120° 00′
Error	19° 26′ E

A still simpler way is to measure the altitude with the sextant and also note the exact time.

Then add together the sine of the hour angle (H. A.), the cosine of the Decl. and the secant of the alt. The sum is the sine of the azimuth.* The H. A. is the L. A. T. or 12^h − L. A. T.

Example. L. A. T., $9^h\ 10^m\ 50^s$; Decl., − 21° 16′; corrected altitude, 15° 23′. Lat., 42° 20′ N. Find the azimuth of the sun.

H. A. = $2^h\ 49^m\ 10^s$ =	42° 17′	log sin	9.82788
Decl. =	−21° 16′	log cos	9.96937
Alt. =	15° 23′	log sec	0.01585
Az. =	40° 34′	log sin	9.81310

* This calculation may be performed by inspection by using Table V of H. O. Publ., No. 200.

This is evidently S 40° 34′ E because with a South Decl. in North Lat. the sun cannot be north of the east point. In case the sun's bearing is nearly East or West it may be necessary to use some other method to determine whether the bearing is to be reckoned from the North or from the South point.

AMPLITUDES

The compass error is often found by observing the sun's amplitude. The amplitude is simply the angular distance of the sun (or star) North or South of the East or West point of the horizon. It is observed by taking the bearing when the lower edge of the sun is apparently half a diameter (16′) above the sea horizon, because at this time the center of the sun is on the true horizon. The amplitude of the sun may be taken from Table 39, Bowditch, for the given latitude and declination.

Example. Lat. 30° N. Compass amplitude of the sun on true horizon E 25° N. Decl., 19° N. Find compass error.

By Table 39, true ampl. =	E 22°.1 N
Compass ampl.	E 25°.0 N
	2° .9 E

If the table is not at hand the true amplitude may be found by

adding together the log secant Lat. and log sine Decl. The sum is the log sine of the amplitude.

Example. Lat. 40° N. Decl. 10° N. Find the true amplitude.

log sec 40°	0.11575
log sin 10°	9.23967
log sin ampl.	9.35542
true ampl. =	13° 06′
=	13°.1

USE OF TABLE 40

If the bearing of the sun is taken when the center is on the sea horizon the observed bearing may be reduced to what it would have been if taken on the true horizon by means of the corrections in Table 40. The correction at rising in North latitudes or setting in South latitudes is applied to the right. At setting in North latitudes or rising in South latitudes, the correction is to the left.

Example. Lat. 30° N; Decl. 10° N; observed amplitude of the sun when on the sea horizon (mean of observed bearings when upper and lower limbs were in contact with the horizon), E 21° N.

Observed ampl.	E 21° N
Corr. Table 40	0.4
Compass ampl.	E 20°.6 N
Table 39, True ampl.	E 11°.5 N
Total Compass Error	9°.1 E

If it is desired to obtain the bearing of the sun at time of sunrise or sunset, the tables at the foot of the page in H. O. Publ. No. 71 will be found very convenient.

A table of deviations may be constructed with but little trouble during a voyage by making a complete loop in the ship's track at about the time of sunset and sighting on the sun when the ship is headed on each point or each two points of the compass. The azimuths may be worked out either by azimuth tables or by tables of amplitudes.

PROBLEMS

1. Find the azimuth of the sun at the time of the sight in prob. 1, p. 127.

2. Find the azimuth of the sun at time of sight in prob. 2, p. 127.

3. Find the azimuth of the sun at time of sight in prob. 3, p. 127.

4. The hour angle of the sun is 34° 46′ (P.M.); Decl., − 22° 45′ 50″; corrected alt., 17° 41′. Find the sun's azimuth. *Ans.* S 33° 20′ W.

CHAPTER XI

SUMNER'S METHOD

WE will now describe Sumner's method of locating the ship, and as this is superior to the older methods the student should make himself perfectly familiar with it. By the older methods the navigator finds, by means of a latitude observation, what parallel he is on, and, by a time sight, what meridian he is on. By means of Sumner's method he finds what "position line" he is on, and this position line may run in any direction whatever. The older method of location is really a special case of Sumner's method.

In order to understand the principle of this method, the student should realize that at any instant of time there must be one place on the earth, and only one place, where the center of the sun (or other observed body) is exactly overhead. If an observer measures the sun's altitude and finds that it is 80°, that is, his Zenith distance is 10°, then he has determined the fact that he is 10° or 600 miles away from this point beneath the sun. If other observers should also find that the sun's Zenith distance was 10° this would mean that all such observers are at the same distance from the point beneath the sun and consequently are all situated on a circle whose center is this point directly beneath the sun, and whose radius is 10° or 600 miles. The measured altitude locates the

ship on this circle, but does not tell what part of the circle the ship is on. If it is possible to get two such circles then the ship must be at the point (one of the two points) where the circles cut each other, since it is on both circles at once.

If such a circle of position were laid down on a chart, by finding the position of the center and the radius, it would be found that any small portion of the circle is so nearly a straight line that the difference between the straight line and the curve is hardly perceptible. In fact it is nearly always considered a straight line in practice. Such a line is called a "line of position" or a "Sumner line." Any altitude that you measure locates you on a Sumner line. Suppose that the point beneath the sun is in latitude 10° North and 30° West and that the corrected altitude is 60°. The Z. D. is therefore 30° and you are 1800 miles from the center of the circle. Laying down this circle on the chart you have the result shown in Fig. 37. You are somewhere on this circle, and if you know that you are very nearly at point *S* then you are practically on the straight line *ab*.

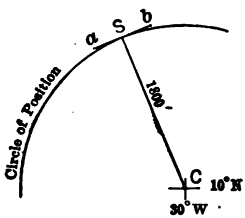


FIG. 37.

The position of the center is given by the position of the sun itself. The latitude of the point, *C*, beneath the sun, is the same as the sun's declination. The longitude of *C* is the same as the sun's hour angle from Greenwich,

that is, the G. A. T. It would be possible, then, to mark on the chart the position of the center, and, using the Z. D. for a radius, to draw the circle or at least that portion of it which we need to use. But it is much more accurate and practical to do this by calculation.

Notice that in the figure the bearing of the center from the ship (which is the same as the sun's bearing) is always at **right angles** to the bearing of the position line itself, that is, the position line is 8 points to the right or left of the sun.

If you observe an altitude, and with some assumed latitude you calculate your longitude, then you have one fixed point on your position line which you can lay down on the chart: Laying off a line at right angles to the sun's true bearing you have the position line laid down; and you know you are somewhere on that line no matter if your assumed latitude was many miles in error.

In calculating the observation we may use several methods. First: We may assume a latitude a little North of where we think we are and calculate the longitude, and mark this position on the chart. Then, assuming a latitude South of where we suppose the ship to be, we calculate another longitude, and mark this position on the chart. The line joining these two points is the line of position and the ship is somewhere on this line. If a second such line is obtained by observing a different body, or the same body at a later time, the ship's true position is at the point where the two lines cross. This point is given the name of "Fix."

Second: An easier way is to make use of the fact that the position line is at right angles to the sun's bearing, and to omit the calculation of the second longitude. In this case we assume our first latitude as near the true position as we can and then calculate the longitude and mark this point on the chart. The sun's bearing is taken from the Azimuth Tables. A line through the marked position and drawn at right angles to the sun's bearing is the position line. To change the sun's bearing into the bearing of the position line, simply change **one** of the letters and take the number of degrees from 90. For example, if the sun bears S 30° E, the Sumner line is either N 60° E, or S 60° W. If a second line can be plotted, from another observation, the ship is at the intersection of the two lines.

Third: The position of the point where the two Sumner lines cross may be calculated by means of "longitude factors," by a method introduced by A. C. Johnson, to be described in detail later.

Fourth: The position may be found by calculating the altitude of the sun corresponding to an assumed position of the ship and comparing this with the altitude actually observed. This is the method of Marcq Saint-Hilaire.

POSITION LINE FROM THE CHRONOMETER SIGHT

As an illustration of this method let us take the observation given on p. 121, but we will assume that our latitude is 44° 30′. Working out the longitude and the sun's bearing we have the following results:

h	33° 44′ 13″		
L	44° 30′ 00″	sec	0.14676
p	67° 31′ 00″	csc	0.03433
	2)145° 45′ 13″		
s	72° 52′ 36″	cos	9.46899
$s - h$	39° 00′ 23″	sine	9.80018
			19.45026

L. A. T.	$4^h\ 16^m\ 36^s$
G. A. T.	$8^h\ 42^m\ 26^s$
Long.	$4^h\ 25^m\ 50^s$
	66° 27′ 30″ W

Az. of sun by Tables, S 89°½ W

Laying down the position on the chart and drawing the position line N ½° W we have the result shown in Fig. 38. The line passes through latitude 44° 43′ 15″, longitude 66° 27′ 45″, which is the true position of the observer.

POSITION LINE FROM A ϕ' ϕ'' SIGHT

In this case the longitude by D. R. is employed to obtain the hour-angle, and the latitude is computed. The position is then plotted and the Sumner line drawn as before.

For example, if the sight on p. 103 is to be worked up for a position line and the longitude is unknown, we might assume a longitude of 66° and then proceed as follows:

G. A. T.	$5^h\ 33^m\ 37^s$				
Lo.	4 24 00				
L. A. T.	$1^h\ 09^m\ 37^s$				
t	17° 24′ 15″	log sec	0.02035		
D	21 33 06	log tan	9.59655	log csc	0.43493
h	62 55 27			log sin	9.94959
ϕ''	22 29′ 05	log tan	9.61690	log sin	9.58256
ϕ'	22 01 36			log cos	9.96708
Lat.	44° 30′ 41″				

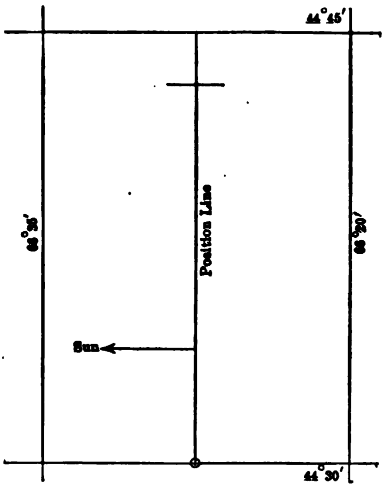

44°45'
66°35'
Position Line
66°20'
Sun
44°30'

FIG. 38.

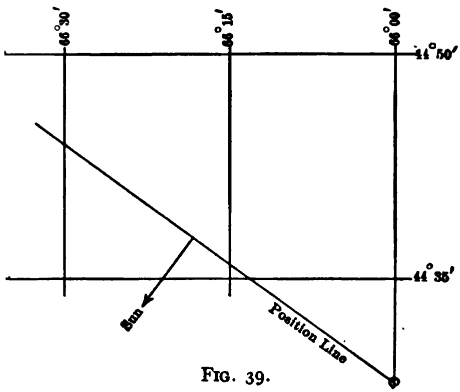

66°30'
66°15'
66°00'
44°50'
44°35'
Sun
Position Line

FIG. 39.

Sun's true bearing, by tables, S 37°½ W. Marking the point and laying out the position line in the direction N 52°½ W we have the result shown in Fig. 39.

When two observations are made on the same body to determine the ship's position, it is necessary to wait until the body has changed its bearing by at least two points, or nearly 30°, in order that the two position lines may cut each other at a favorable angle for getting an accurate position, or "fix." During this interval the ship will alter her position, and this makes it necessary to alter the position of the first Sumner line so that the two lines will correspond to the same moment of time. This is done by selecting any point on the first position line and drawing from it a line representing the course and distance sailed between the observations. The extremity of this line is a point on the corrected Sumner line. If now a line be drawn parallel to the first line and passing through this point it will contain the ship's position at the time of the second observation. The point where the second Sumner line cuts this corrected line is the "fix."

Example. At sea, Jan. 4, 1910, at chro. time $1^h\ 12^m\ 48^s$ the obs. alt. $\underline{\odot}$ was 15° 53′ 30″; I. C., 0″; ht. of eye, 36 ft.; C. C., -15^s; Lat. by D. R., 42° 00′ N. Computing the Long. we get 55° 35′ 30″; sun's bearing S 36° ¾ E. The position line is as shown in Fig. 40. Between this sight and the P.M. sight the ship runs N 89° W, 45 miles. Assuming a point x on the position line we draw a line running N 89° W, 45 miles, which gives point y. Through y draw a line parallel to the first

position, giving the Sumner line we would have found if the ship had been here at the time of the first sight. At chro. time $6^h\ 05^m\ 46^s$ the sun's alt. was $17°\ 33'\ 30''$; I. C., $0''$; ht. of eye, 36 ft.; C. C., $-\ 15^s$. The resulting longi-

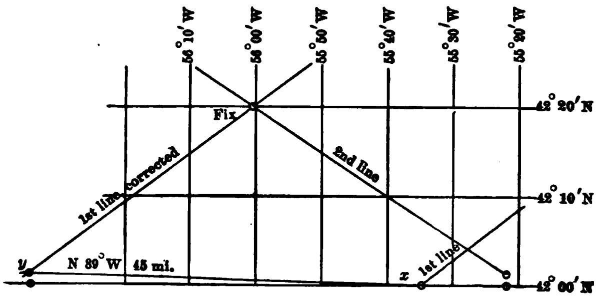


FIG. 40.

tude is $55°\ 22'$ W and the sun's bearing S $33° \frac{1}{2}$ W. The position line is as shown in Fig. 40. The lines cross at Lat. $42°\ 20'.1$, Long. $56°\ 01'.2$, which is the true position of the ship at the second observation.

Position plotting sheets may now be obtained which are made especially for laying down Sumner lines. They extend over 4°, 5°, or 6° of latitude, according to the latitude of the parallels shown, and over 10° of longitude. Since the longitude degrees are all equal on the chart these sheets may be used in any longitude. Fixing the position by plotting the Sumner lines is the most rapid way of obtaining the ship's position.

POSITION OF THE "FIX" BY COMPUTATION

The position of the ship may be computed more accurately than it can be taken off the chart, by the use of so-called "Longitude factors." We first correct the assumed position for run as follows:

Lat. by D. R.	42° 00′ N	Long. by Comp.	55° 35′ 30″
Diff. Lat.	00′ 48″ N	D. Lo.	1 00 30
Cor'd. Lat.	42° 00′ 48″ N	Cor'd. Long.	56° 36′ 00″

From the second observation we have:

Lat. by D. R., 42° 00′ 48″ N; Long. by Comp., 55° 22′ 00″ W.

The discrepancy in the longitudes is 74′.0. From Table 47, Bowditch, with Lat. 42° and bearing 36°¾ we find 1.80 for the longitude factor of the first position line; for the second line, Lat. 42° and bearing 33°½, the factor is 2.03. These factors show the change in longitude for a 1′ change in latitude as we go along the Sumner line. For example, if we go along the first line in a northeasterly direction so as to increase our Lat. 1′ we shall decrease our Long. 1′.80. For the second line an increase of 1′ in Lat. produces an increase of 2′.03 of Long.

To find the difference between the assumed Lat. (42° 00′ 48″) and the latitude of "Fix" divide the discrepancy in longitude by the sum of the longitude factors. The result is the correction to the D. R. Lat. at the second observation.

In our example $74'.0$ divided by $3.83 = 19'.3$, the corr. to Lat. The Lat. of "Fix" is therefore $42° 00'.8 + 19'.3 = 42° 20'.1$ N.

To correct the longitudes multiply each Long. factor by the corr. to Lat. This gives two corrections which are to be applied to the longitudes. The two results for the longitude of the ship should agree if the work is correct.

Making these corrections the position of the ship is found to be Lat. $42° 20'.1$ N. Long. $56° 01'.2$ W. The complete computation of the ship's position is given on pp. 149 to 152.

Chro.	$1^h\ 12^m\ 48^s$
C. C.	-15
	$1^h\ 12^m\ 33^s$
Eq. t.	$-4\ \ 51$
G. A. T.	$1^h\ 07^m\ 42^s$

Alt. $\underline{\odot}$	$15^\circ\ 53'\ 30''$
	$+7\ \ 13$
h	$16^\circ\ 00'\ 43''$
Table 46	$+6'\ 55''$
	$+18$
Corr.	$+7'\ 13''$

Cor'd Decl.	$-22^\circ\ 47'\ 04''$
p	$112^\circ\ 47'\ 04''$
Cor'd Eq. t.	$-4^m\ 51^s$
Sun's Az.	S $36^\circ\ 48'$ E
Long. factor	1.80

h	$16^\circ\ 00'\ 43''$		
L	$42\ \ 00\ \ 00$	sec	0.12893
p	$112\ \ 47\ \ 04$	csc	0.03528
	$2)170^\circ\ 47'\ 47''$		
s	$85^\circ\ 23'\ 54''$	cos	8.90434
$s-h$	$69^\circ\ 23'\ 11''$	sin	9.97127
			19.03982
		L. A. T.	$21^h\ 25^m\ 20^s$
		G. A. T.	$25\ \ 07\ \ 42$
		Long.	$\left.\begin{cases} 3^h\ 42^m\ 22^s \\ 55^\circ\ 35'\ 30'' \end{cases}\right\}$ W

Course	Dist.	N	W	D. Lo.
N 89° W	45	0.8	45.0	60.5

Lat. D. R.	42° 00′ 00″ N	Lo.	55° 35′ 30″ W
Run	48″ N	Run	1° 00′ 30″ W
Cor'd Lat.	42° 00′ 48″ N	Cor'd Lo.	56° 36′ 00″ W

Chro.	$6^h\ 05^m\ 46^s$	Alt. $\odot$	$17°\ 33'\ 30''$	Cor'd Decl.	$-22°\ 45'\ 50''$
C. C.	-15	Corr.	$+7\ \ 32$		
G. M. T.	$6^h\ 05^m\ 31^s$	h	$17°\ 41'\ 02''$	p	$112°\ 45'\ 50''$
Eq. t.	$-4\ \ 57$			Cor'd Eq. t.	$4^m\ 57^s$
G. A. T.	$6^h\ 00^m\ 34^s$	Table 46	$+7'\ 14''$	Sun's Az.	S $33°\ 30'$ W
			$+18''$		
		Corr.	$+7'\ 32''$	Lo. factor	2.03

h	$17°\ 41'\ 02''$		
L	$42°\ 00'\ 48''$	sec	0.12902
p	$112°\ 45'\ 50''$	csc	0.03521
	$2)\underline{172°\ 27'\ 40''}$		
s	$86°\ 13'\ 50''$	cos	8.81786
$s-h$	$68°\ 32'\ 48''$	sin	9.96882
			18.95091
		L. A. T.	$2^h\ 19^m\ 06^s$
		G. A. T.	$6\ \ 00\ \ 34$
		Long.	$\left.\begin{cases} 3^h\ 41^m\ 28^s \\ 55°\ 22' \end{cases}\right\}$ W

Lo. 1.	56° 36′.0	19.1 × 1.80 = 34.7	1st corr.
Lo. 2.	55 22 .0	19.1 × 2.00 = 39.2	2nd corr.
	1° 14′.0		

$$\frac{74.0}{1.80 + 2.03} = 19'.3 \text{ corr. to Lat.}$$

Lo. 1.	56° 36′.0	Lo. 2.	55° 22′.0
Corr.	34 .7	Corr.	39 .2
Lo.	56° 01′.3	Lo.	56° 01′.2

D. R. Lat.	42° 00′.8		
	19 .3		
Lat. of Fix	42° 20′.1	Lo. of Fix	56° 01′.2

NOTE.—If the sun had been on the same side of the meridian at both observations it would have been necessary to divide the discrepancy in longitude by the difference in the longitude factors.

To work this same problem by Saint Hilaire's method we proceed as follows:

> **Assume a Lat. and Long. and from the chro. time compute the L. A. T. Add together the log. haversine of the L. A. T., the log cos Lat., the log cos Decl. The result is the log hav of an angle θ. The angle itself is not needed, but we take out the *natural* haversine, which is found abreast of the log hav in the same table. Add to the nat hav θ the nat hav $L \sim D$. The result is the nat hav Z, the zenith distance. To find $L \sim D$, take the difference between L and D if they are of the same name, but take the sum if of different names. The calculated altitude is Z subtracted from 90°. The difference between the observed and calculated h is the *altitude difference*.**

The assumed point is to be moved by this amount **toward** the observed body if the observed altitude is **greater** than the calculated alt.; **away** from it if the observed alt. is **less**. Since we know the bearing of the sun and the number of miles the point is to be moved we may calculate the difference in the Lat. and Long. by means of the traverse table. The Sumner line is the line at right angles to the bearing of the observed body and passing through this new point.

FIRST OBSERVATION

Assuming a Lat. 42° 00′ and a Long. of 56° 30′ we calculate the altitude.

Chro. T.	$1^h\ 12^m\ 48^s$	Alt. $\odot$	$15°\ 53'\ 30''$	Cor'd Decl.	$-22°\ 47'\ 04''$
C. C.	-15	Corr.	$+7\ 13$	Cor'd Eq. t.	$-4^m\ 51^s$
G. M. T.	$1^h\ 12^m\ 33^s$ Jan. 4	h	$16°\ 00'\ 32''$	Sun's Az.	S $36°\ 48'$ E
or	25 12 33 Jan. 3			Long. factor	1.80
Lo.	3 46 00	Tab. 46	$+6'\ 55''$		
L. M. T.	$21^h\ 26^m\ 33^s$		$18''$		
Eq. t.	$-4\ 51$	Corr.	$+7'\ 13''$		
L. A. T.	$21^h\ 21^m\ 42^s$				

L. A. T.	$21^h\ 21^m\ 42^s$	log hav =	9.05920
L	$42°\ 00'$ N	log cos =	9.87107
D	$22°\ 47'\ 04''$ S	long cos =	9.96471
		θ log hav	8.89498
		θ nat hav	0.07852
$L \sim D$	$64°\ 47'\ 04''$	nat hav	0.28698
Z	$74°\ 23'.7$	nat hav	0.36550

Calc. h	$15°\ 36'.3$
Obs. h	$16°\ 00'.7$
Alt. diff.	$24'.4$

Since the observed altitude is higher than the calculated latitude the observer's position is nearer to the sun than the assumed position. The assumed position, 42° 00′ N, 56° 30′ W, must be moved S 36° 48′ E, 24.4 miles. This may be done by means of the traverse table (Table 2).

Course	Dist.	S	E	D. Lo.
S 37° E	24.4	19.5	14.6	19.6

$$\begin{array}{lrl} & 42^\circ\ 00' & \text{N} \\ & 19.5 & \text{S} \\ \hline \text{Lat. of } S & 41^\circ\ 40'.5 & \text{N} \end{array} \qquad \begin{array}{lrl} & 56^\circ\ 30' & \text{W} \\ & 19.6 & \text{E} \\ \hline \text{Long. of } S & 56^\circ\ 10'.4 & \text{W} \end{array}$$

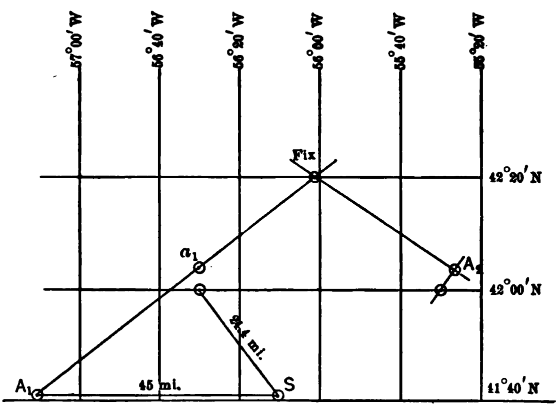


FIG. 41.

This gives a point S on the first position line (Fig. 41). This position is next corrected for the run of the ship, as follows:

Course	Dist.	N	W	D. Lo.
N 89° W	45	0.8	45.0	60.5

S	41° 40′.5 N	56° 10′.4 W
run	0 .8 N	1 00 .5 W
A_1	41° 41′.3 N	57° 10′.9 W

This gives a Sumner line passing through this point marked A_1, and running S 53° W.

SECOND OBSERVATION

Assuming a Lat. 42° 00′ N, Long. 55° 30′ W, we calculate the altitude as follows:

Chro. T.	$6^h\ 05^m\ 46^s$		Alt. ⊙	17° 33′ 30″		Cor'd Decl.	−22° 45′ 50″
C. C.	−15		Corr.	+7 32			
G. M. T.	6 05 31	Jan. 4	h	17° 41′ 02″		Cor'd Eq. t.	$-4^m\ 57^s$
Lo.	3 42					Sun's Az.	S 33° 30′ W
L. M. T.	2 23 31		Tab. 46	+7′ 14″		Long. factor	2.03
Eq. t.	−4 57			+18			
L. A. T.	2 18 34		Corr.	+7′ 32″			

L. A. T.	$2^h\ 18^m\ 34^s$	log hav	8.94762
L	42° 00′ 00″ N	log cos	9.87107
D	22° 45′ 50″ S	log cos	9.96478
		θ log hav	8.78347
		θ nat hav	0.06074
$L \sim D$	64° 45′ 50″	nat hav	0.28682
Z	72° 15′	nat hav	0.34756

Calc. h	17° 45′
Obs. h	17° 41′ 02″
Alt. diff.	4′.0

Since the observed alt. is lower than the calculated alt. the observer is farther away from the sun than the position assumed. The point in Lat. 42° 00′ N, Lo. 55° 30′ W, must be moved 4.0 miles N 33° E.

Course	Dist.	N	E	D. Lo.
N 33° E	4	3.4	2.2	3.0

	42° 00′ N	55° 30′ W
	3.4 N	3′.0 E
A_2	42° 03′.4 N	55° 27′.0 W

The position line through A_2 runs N 57° W.

To compute the position of the point of intersection (Fix) we must first bring the latitude of A_1 up to that of A_2 (Fig. 41).

A_2	42° 03′.4
A_1	41° 41′.3
Diff.	22′.1

To find the change in longitude corresponding to difference in latitude 22′.1 multiply by the Long. factor for the line through A_1.

```
  22.1
  1.80
 17680
 221
 39.780 D. Lo.
```

Lo. A_1	57° 10′.9 W
D. Lo.	39′.8 E
Lo. of a_1	56° 31′.1

The remainder of the work is the same as in the preceding method; that is, divide the discrepancy in longitude by the sum (or difference) of the Lo. factors to get the correction to the latitude.

Lo. A_1	56° 31′.1 W	
Lo. A_2	55° 27′.0 W	
D. Lo.	1° 04′.1	= 64′.1

```
3.83)64'.1  (16'.7
     38 3
     25 80
     22 98
      2 820
      2 681
```

	42° 03′.4
	16′.7
Lat. of Fix	42° 20′.1

To find the Longitude multiply the correction to Latitude by both Longitude factors and correct each Longitude.

```
16'.7        16'.7
 1 .80        2 .03
13 360          501
16 7         33 4
30'.060      33'.901
```

Lo. a_1	56° 31′.1	Lo. A_2	55° 27′.0
	30′.1		33′.9
	56° 01′.0		56° 00′.9

Longitude of Fix 56° 01′.0

One of the advantages of Saint Hilaire's method is that we always proceed in the same way, no matter whether we are dealing with a time sight, a $\phi'\phi''$ sight, or an ex-meridian.

In the preceding examples we have taken both sights on the same body, the sun. The position of **Fix** is uncertain by any error in the run between sights. If, however, we can observe two bodies at one time, or within a few minutes of each other, we have the position of the ship at once. For example, we might observe the sun and the moon, a planet and the moon, or two fixed stars.

EXAMPLE OF SUMNER'S METHOD BY TWO STARS

Let us take the ϕ' ϕ'' sight on *Antares* and the chronometer sight on *Arcturus* already worked out on p. 113 and p. 125. Assuming a latitude of 44° 40′ N and longitude 66° 25′ W we find for the longitude from Arcturus 66° 19′ 46″; the star's bearing is S 79°½ W and its Long. factor is 0.25. For Antares the computed latitude is 44° 47′ 00″; the azimuth is S 19°½ W and the Long. factor is 3.96. From the two Sumner lines the ship is found to be in latitude 44° 46′ 04″ N, longitude 66° 21′ 18″ W.

AQUINO'S METHOD

This method consists in treating the Sumner lines in the same manner as described under St. Hilaire's method, but using spherical traverse tables to shorten the process. The necessary tables will be found in Hydr. Office publ.

No. 200. In order to make the method clear we will work the problem stated on p. 145.

Since it makes no difference in the final result whether we use the D. R. position for plotting the line or some other (assumed) position, we will select a point in such a position that much interpolation in the tables will be avoided.

Working out the G. A. T. of the first observation, and combining it with the D. R. Long., we obtain the hour angle of the sun (L. A. T.) which we will call $t_{D.R.}$

Chro.	$1^h\ 12^m\ 48^s$
C. C.	-15
G. M. T.	1 12 33
Eq. t.	$-4\ 51$
G. A. T.	1 07 42
	$= 16°\ 55'.5$
$Lo._{D.R.}$	$= 55\ 55\ .5$
$t_{D.R.}$	$= 39°\ 00'.0$

Next we take from the table a factor a, which is given for every 30′. It will be advantageous to use a value of a which is an exact degree or an exact half-degree, so we enter the table at the **bottom** with the approximate declination = 23° and the hour angle = 39°, and find that the value of a, to the nearest 30′, is 35° 30′. Now, working the process backward, enter the table from the **top** and using the value 35° 30′ for a, and the exact declination, $d = 22°\ 47'.1$, take out the numbers b and t. Here it is necessary to interpolate for the minutes and the work is given in full below.

$$b = 28° + \frac{19.1}{47} \times 60' = 28° \ 24'.4$$

$$t = 38° \ 56' + \frac{19.1}{47} \times 16' = 39° \ 02'.5.$$

The 19.1 is the difference between the Decl. and the next smaller Decl. in the table; the 47 is the difference between the two declinations given in the table. The 60′ is the difference between the two values of b in the table (1°); the 16′ is the difference between the two values of t in the table. Since the value of t is not the real value but is an **assumed** value we shall call it t_A.

We are next to add our Lat. and the number b to get the number C. (Add because the Lat. and Decl. are of opposite names.)* In order to make C a whole degree we change the minutes of the Lat. as follows:

$$\begin{aligned} \text{Lat.}_A &= 41° \ 35'.6 \\ b &= \underline{28° \ 24'.4} \\ C &= 70° \ 00' \end{aligned}$$

This new Lat. is called Lat.$_A$ (Lat. assumed) to distinguish it from the Lat. by D. R.

With $C = 70°$ and $a = 35° \ 30'$, we take from the table $h = 16° \ 10'$ and $Z = 37° \ 12'$, which are **exact** values corresponding to the position we assumed. The value of h is called h_c (calculated alt.); Z is the sun's azimuth and is marked S 37° 12′ E.

* If the Lat. and Decl. are of the *same* name we take the difference between Lat. and b. In case, however, the hour angle is greater than 90°, C is 180° less the sum of Lat. and b. (See H. O. 200, p. 189.)

In order to find the Long. of this assumed position we add the G. A. T. to t_A, obtaining

$$\begin{array}{rl} t_A & 39^\circ\ 02'.5 \\ \text{G. A. T.} & \underline{16\ \ 75\ .5} \\ \text{Long.}_A & 55^\circ\ 58'.0 \end{array}$$

Correcting our observed alt. $\underline{\odot}$ (15° 53′ 30″) as usual we have h_o = 16° 00′ 43″, or 16° 00′.7. Taking the difference between this and h_c we have the alt. diff.

$$\begin{array}{rl} h_c = & 16^\circ\ 10' \\ h_o = & \underline{16\ \ 00\ .7} \\ \text{alt. diff.} = & \qquad 9'.3, \text{ away from the sun.} \end{array}$$

As a result of these calculations we have a point in Lat. 41° 35′.6 N., Long. 55° 58′.0 W., which must be moved 9′.3, N 37° 12′ W. to place it on the Sumner line; then it must be moved 1′ N., and 60′ W. to allow for the run of the ship to the second observation. The work is given below.

Course	Dist.	N	W	D. Lo.
N 37°12′ W	9′.3	7.5	5.5	7.4

$$\begin{array}{rl} \text{Lat.}_A & 41^\circ\ 35'.6\ \text{N} \\ & \underline{7.5}\ \text{N} \\ \text{Lat.} & 41^\circ\ 43.1\ \text{N} \\ \text{Run} & \underline{1.0}\ \text{N} \\ \text{Lat.} & 41^\circ\ 44'.1\ \text{N} \end{array} \qquad \begin{array}{rl} \text{Long.}_A & 55^\circ\ 58'.0\ \text{W} \\ & \underline{7\ .4}\ \text{W} \\ \text{Long.} & 56^\circ\ 05'.4\ \text{W} \\ \text{run} & \underline{1\ \ 00\ .0}\ \text{W} \\ \text{Long.} & 57^\circ\ 05'.4\ \text{W.} \end{array}$$

The process of working out the second observation is similar and is given in condensed form below.

Chro.	$6^h\ 05^m\ 46^s$
C. C.	$-\ 15$
G. M. T.	$6\ 05\ 31$
Eq. t.	$-\ 4\ 57$
G. A. T.	$6\ 00\ 34$
	$= 90°\ 08'.5$
Lo.	$57\ 05'.4$
$t_{D.R.}$	$33°\ 03'.1$

With $d = 23°$ and $t = 33°$ (bottom of page) take out $a = 30°$. With $a = 30°$ and $d = 22°\ 45'.8$ (top of page) take out $b = 26°\ 32'.1$ and $t_A = 32°\ 50'.5$. The interpolation is as follows:

$$b = 26° + \frac{26.8}{50} \times 60 = 26°\ 32'.1.$$

$$t_A = 32°\ 43' + \frac{26.8}{50} \times 14 = 32°\ 50'.5$$

In order to make C a whole degree we change our Lat. as shown below

$$\begin{aligned} b &= 26°\ 32'.1 \\ \text{Lat.}_A &= 41\ \ 27.9 \\ C &= 68°\ 00.'0 \end{aligned}$$

With $C = 68°$ and $a = 30°$ take out $h_c = 18°\ 56'$ and $Z = 31°\ 55'$. Then

t_A	$= 32°\ 50'.5$	h_c	$= 18°\ 56'$
G. A. T.	$= 90\ \ 08\ .5$	h_o	$= 17\ \ 41.0$
Long.$_A$	$= 57°\ 18'.0$	alt. diff	$=\ 1°\ 15'.0$
			$= 75'$ away from sun.

Our point in Lat. 41° 27′.9 N, Long. 57° 18′.0 W, must be moved 75′, N 31° 55′ E.

Course	Dist.	N	W	D. Lo.
N 31° 55′ W	75′	63.6	39.7	53.4

Lat.$_A$	41° 27′.9 N	Long.$_A$	57° 18′.0 W
	1 03′.6 N		53′.4 E
Lat.	42° 31′.5 N	Long.	56° 24′.6 W

The point in Lat. 41° 44′.1 N, Long. 57° 05′.4 W is on a position line bearing N 52° 48′ E, and the Long. factor is 1.77. The point in Lat. 42° 31′.5 N, Long. 56° 24′.6 W is on a position line bearing N 58° 05′ W, the Long. factor being 2.15. We now intersect these lines either on the chart, as explained on p. 145, or by computation as explained on p. 147. Running the first point up to the Lat. of the second point, we have the following position.

Lat.$_2$	42° 31′.3	Lo.$_1$	57° 05′.4
Lat.$_1$	41° 44′.1	Long. corr.	1° 23′.5
D. Lat.	47′.2	Long.	55° 41′.9

47′.2 × 1.77 = 83′.5 = 1° 23′.5 = Long. corr.

Dividing the discrepancy in longitude by the sum of the factors we obtain the correction to the Lat.

Lo.$_2$	56° 24′.6	$\frac{42'.7}{3.92} = 10'.9$, Lat. corr.
Cor'd Lo.$_1$	55 41 .9	
Discrepancy	42′.7	

Lat.	42° 31′.3
Corr.	10 .9
Lat of Fix.,	42° 20′.4 N

To correct the longitudes multiply the corr. to Lat. by each Long. factor and apply the two corrections to the corresponding longitudes.

$$10'.9 \times 1.77 = 19.3$$
$$10'.9 \times 2.15 = 23.4$$

Long.	56° 24′.6	Long.	55° 41′.9
Corr.	23 .4	Corr.	19 .3
Long. of Fix.	56° 01′.2	Long. of Fix.	56° 01′.2

SECOND METHOD

By employing another method, quite similar to the one just described, it is possible to avoid the interpolation for b and t. Beginning at the point where we have found a to be 35° 30′ (first observation), enter the table with a at the top and the **nearest** value of d at the left, which in this case is 22° 28′ (called d'). Corresponding to this value we find in the table $b = 28°$ and $t = 38° 56'$. Combining b and L as before we have

$$\begin{aligned} b &= 28° 00' \\ L_A &= \underline{42 \quad 00} \\ C &= 70° 00' \end{aligned}$$

Now with $a = 35° 30'$ and $C = 70°$ take out the values of h and Z. These are called h' and Z', approximate values of h and Z which must be corrected because we used $d' = 22° 28'$ instead of $d = 22° 47'.1$. The numbers taken from the table are $h' = 16° 10'$ and $Z' = 37° 12'$. The correction to Z' may be neglected, as it is too small to affect the final position. The error in h', called Δh, must be found and applied.

In order to find Δh, we need to know the numbers α and β. These may be taken from the same table. When we take out b and t, $\alpha = 73°$ will be found in the right-hand column and on the same line. When taking out h' and Z', $\beta = 78°.2$ is found in the same column as α and on the same line as h' and Z'. Adding α and β we get $M = 151°.2$. (See rules on p. 189, H. O. 200.) To find the value of Δh per minute of declination enter Table VII with $90° - M$, or $-61°.2$, in the column marked Z'; in the second column we find the number 0.88. This number multiplied by $19'.1$, the difference between d' and d, gives $16'.9$ as the altitude correction, Δh.* According to the rule on p. 194, H. O. 200, Δh has the opposite sign to Δd, where

$$\Delta d = d - d'.$$

Since d is larger than d', Δd is $+$ and therefore Δh is $-$.

Correcting h' we have

$$\begin{aligned} h' &= 16°\ 10' \\ \Delta h &= \underline{\ -\ 16.9\ } \\ h_c &= 15°\ 53'.1 \\ h_o &= \underline{16°\ 00'.7} \\ \text{Alt. dif.} &= \quad 7'.6 \text{ toward the sun.} \end{aligned}$$

$$\text{Sun's bearing} = \text{S } 37°\ 12' \text{ E.}$$

* This correction may be obtained directly by the use of a special table included in a pamphlet "To Accompany Aquino's 'Newest' Navigation" by Henry Howard, Boston, 1917.

The assumed Lat. is 42° 00′ N; to find the corresponding Long. we combine the approximate value of t with the G. A. T., giving

$$\begin{array}{rl} t & = 38^\circ\ 56' \\ \text{G. A. T.} & = \underline{16\ \ 55\ .5} \\ \text{Lo.}_A & = 55^\circ\ 51'.5\ \text{W} \end{array}$$

Making the correction for 7′.6 of altitude and then correcting for run, as before, we obtain:

Lat.$_A$	42° 00′ N	Lo.$_A$	55° 51′.5 W
	6′.1 S		6′.2 E
	41° 53′.9 N		55° 45′.3 W
run	1′.0 N	run	1° 00′.0 W
Lat.$_A$	41° 54′.9 N	Lo.$_A$	56° 45′.3 W

The Sumner line through this point and at right angles to the sun's bearing should coincide with the line found by the first method.

USES OF A SINGLE SUMNER LINE

Attention should be called to the fact that a single Sumner line gives much information in regard to the position of the ship. Suppose we are nearing the land and a sight shows that the Sumner line passes through A, and has a bearing S 40° W (Fig. 42), and that this line runs directly for the port we wish to reach. We then know the course to steer, although we do not know the exact distance. If, on the other hand, the Sumner line runs directly for some point of danger we know its direction and are able to avoid the danger.

A Sumner line which happens to be about parallel to the shore line gives us the approximate distance off shore.

If a position line runs toward a point of danger *A*,

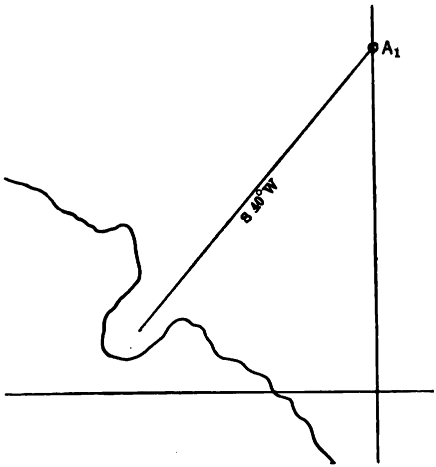


FIG. 42.

(Fig. 43), and it is desired to make some other point *B*, a parallel position line may be drawn through *B*, and the distance between the two lines scaled off by means of the dividers. If the ship sails from S_1 to S_2, at right angles to the position line, she is then on a line of known bearing which passes through the point it is desired to reach. She may be at any point whatever on this line, but the direction to be steered is known.

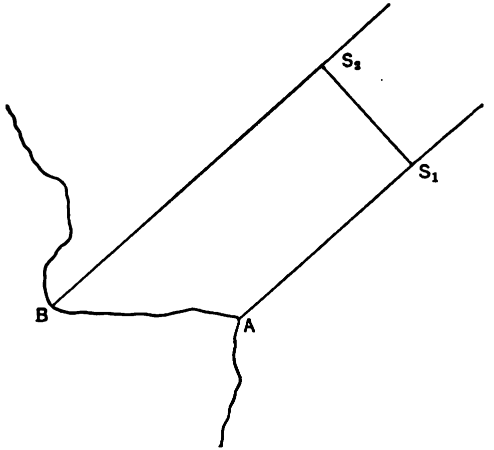


FIG. 43.

POSITION BY A SUMNER LINE AND A LATITUDE AT NOON

A special case of Sumner's method consists in working up an A.M. chronometer sight with an assumed latitude and then correcting the longitude (by the Long. factor) when the true latitude is found at noon.

Example. Corrected altitude, 56° 00′ 12″; corrected declination, 21° 43′ 30″ N; D. R. latitude, 44° 00′ N; G. M. T., $2^h\ 28^m\ 26^s$; corrected equation of time, $-\ 5^m\ 36^s$. Working this sight we find, longitude, 66° 51′ W; Azimuth of sun, S 59°½ E; Long. factor, 0.80. The run to noon is W ¼ N, 11 mi. The corrected latitude is 44° 00′.5 N, the corrected longitude is

$67^\circ\ 06'.3$ W. At noon the latitude is found by observation to be actually $44^\circ\ 43'$ N. The correction to the longitude is therefore $42'.5 \times 0.82 = 34'.0$, which gives $66^\circ\ 31'.4$ W for the corrected longitude at noon. It should be noticed that since the sun bears S $59^\circ \frac{1}{2}$ E the Sumner line runs N $30^\circ \frac{1}{2}$ E. An increase in latitude, therefore, causes a decrease in longitude, so the correction must be subtracted.

COMPASS ERROR FROM BEARING OF SUMNER LINE

Since it is necessary to look up the true bearing of the sun when laying down a Sumner line we may take this opportunity to find the compass error. If the compass bearing of the sun is read at the same time as the altitude the compass error may be found at once. If the compass bearing is taken later it is only necessary to allow for the change in bearing due to the number of minutes elapsed.

Example. In the example on p. 149 the sun's bearing was S $36^\circ\ 48'$ E. Suppose that the compass bearing of the sun had been taken 5 minutes later; from the table we see that the bearing decreases $2^\circ\ 05'$ in 10^m; the bearing 5^m after the sun observation is therefore S $35^\circ\ 45'$ E.

PROBLEMS

1. Correct the longitude found in the problem on p. 142, using latitude $44^\circ\ 43'\ 15''$.

2. Work out the position from the observations on two stars (p. 160), using the three different methods (graphical, computation, and St. Hilaire's).

CHAPTER XII

NAVIGATING THE SHIP

IN the foregoing pages we have discussed the various problems which occur in locating the ship by dead reckoning or by observation. It now remains to show how these may be applied during the day's work of the navigator.

Before leaving port the navigator should ascertain the height of his eye above the water line at all places on the vessel where he expects to take sextant observations.

One of the most important matters to be attended to before going out of sight of land is to "take the departure." This consists in fixing the position of the ship from some definite landmark of known position, to serve as the beginning point of the traverse which is to be kept by dead reckoning. If the vessel passes close to a lighthouse the position of the lighthouse may be used as the point of departure. If the vessel is some distance away from the lighthouse her position may be fixed by a 4-point bearing, or by any of the methods described in Chapter IV. If two objects are visible the ship may be located accurately by means of cross bearings. The log should be read at this time and the vessel set on the first course that she is to sail for her destination. The position of the point of departure and a note of how it was determined should be entered in the log book.

At the time of taking the departure the ship's clocks, which would be regulated to the time used at the port, should be set to the local apparent time of the meridian of the point of departure.

The error and the rate of the chronometer should be known from comparisons made at this port and also on previous occasions. The correction for each day during the voyage may now be figured out so that the correction for the time of any observation may be taken out at once.

The least amount of work which would be required daily in the routine of navigating the ship would consist of (1) working up the dead reckoning for the day's run, including the D. R. position at each sight, the course and distance made good, and the current for the 24 hours; (2) an A.M. sight for longitude and an azimuth to determine the compass error; (3) a noon sight (or an ex-meridian) for latitude; (4) a P.M. sight for longitude.

THE A.M. SIGHT

This should be taken when the sun is near the prime vertical (bearing true E or W). By estimating roughly beforehand the position the ship will be in at 8 A.M. the navigator may find from his Azimuth tables the local apparent time when the sun's true bearing is 90°. The observation should be made at or near this time. In winter the sun passes the prime vertical before sunrise. At this time of year the sight must therefore be taken after the sun has risen 10° or more above the horizon. The hack chronometer should be compared with the

standard chronometer obtaining the chro. corr.; then the observing watch is compared with the hack, obtaining C – W. The sextant, watch, and note book are carried to the place of observation and the sight taken as previously described. The I. C. should be determined just before or just after the altitudes are measured. The patent log should be read while the sight is being taken, and its reading recorded in the same note book. As soon as possible after the sight is taken the compass bearing of the sun (by standard compass) should be observed, using the same watch to note the time.

When working up the morning sight we may proceed in one of three ways. (1) We may work up the sight and plot the Sumner line, using the D. R. Lat. in the computation; this may be combined with any other Sumner line taken later. (2) We may compute the longitude by using the D. R. Lat. and correct it at noon, as explained on p. 170. (3) We may delay working up the sight until noon, when we shall have an accurate latitude by observation; by working the traverse backward from this accurate noon latitude we obtain an accurate latitude at the time of the A.M. sight with which to work out the longitude. This latter is the way the longitude was usually obtained before Sumner's method came into general use. These computations of longitude, as well as that of the noon sight and the traverse should be made in a special "work book" kept for the purpose.

The compass error should be worked out at once and the resulting deviation compared with that given in the

deviation table. When the next course is set the chart should be consulted for any change in the variation.

Since clouds may interfere with taking the latitude exactly at noon it is advisable to take a sight say about 2 hours after the A.M. sight, when the sun has changed its bearing 30° or more. If the noon observation is lost this sight may be worked up as a $\phi'\phi''$ sight. This will give an approximate latitude. Or, better still, the Sumner line may be plotted on the plotting sheet and the position found by the intersection of the two lines.

NOON OBSERVATION

At about 11^h or $11^h\ 30^m$ A.M. the ship's clock and the observing watch should be set as closely as possible to the local apparent time of the meridian where the ship will be at noon. This cannot be done exactly but the setting may be made closely enough for practical purposes.

Suppose that the vessel is going west. In this case the watch must be set back by an amount equal to the change in longitude expressed in units of time. The interval of time to noon will really be that much greater than the amount indicated by the L. A. T. of the A.M. sight. That is, if the sight were taken at 8 : 00 A.M. the time to noon would be 4^h if the vessel did not change her longitude; but since she sails west, noon will occur a few minutes later, and the interval of time to noon will be more than 4^h.

If the vessel is going east the time of noon will occur earlier and this change of longitude must be subtracted to obtain the true interval to noon.

Unless the change in longitude is very rapid it will not be necessary to correct the longitude difference for this change in the interval to noon merely for the purpose of taking the noon sight.

Example (from Bowditch). Suppose that the position at A.M. sight is Lat. 38° 03′.2 N, Long. 72° 50′ 26″ W; watch, 8^h 00^m $03^s.5$; L. A. T., 8^h 17^m $23^s.9$; course, 66°; speed, 11.7 knots per hour. The interval to noon is 12^h less 8^h 17^m $23^s.9$ = 3^h 42^m $36^s.1$, or $3^h.71$. Entering the traverse tables with course 66° and speed 11.7 mi., the dep. is 10′.69, which, in Lat. 38°, gives a D. Lo. of 13′.6 per hour. Multiply $3^h.71$ by 13′.6 gives 50′.46 (= 3^m $21^s.8$), the change in longitude to noon. This is the amount the watch must be set ahead. Since, however, the watch was already 17^m $20^s.4$ slow it must be set ahead 17^m $20^s.4$ + $3^m 21^s.8$ = 20^m $42^s.2$. This process does not take account of the change of time during the 3^m 21^s, but that amounts to only 3^s and has no appreciable effect on the noon observation. If desired it may be taken into account by shortening the run to noon by 3^m 21^s and working out the change in longitude again. The result would be 3^m $18^s.6$.

Now that the watch is set and the noon position is approximately known in advance the navigator may compute the "latitude constant" for the meridian altitude of that date and be ready to take his altitude as soon as the watch reads noon.

It is recommended that the chronometer be wound at this time, since it is more likely to be wound at regular intervals, and is less likely to be forgotten.

When the watch indicates 12^h the noon altitude of the sun is read and the latitude obtained at once. If there is any doubt, however, about the time, it is always safe to take the highest altitude as the meridian altitude.

If it is somewhat cloudy just before noon it is well to take an ex-meridian say 25^m to 15^m before noon, to be used in case the noon observation itself is lost.

Having obtained the latitude by observation the next step is to bring the A.M. longitude up to noon. If the A.M. longitude was worked up by using a correct latitude (carried back from noon) it is only necessary to apply to the A.M. longitude the run to noon. This result is called the Long. at noon *by observation*, to distinguish it from the Long. at noon by D. R., which is computed entirely by dead reckoning. If the A.M. longitude was worked up by use of an assumed latitude or a Lat. by D. R. the longitude should first be corrected for the run to noon, and then corrected for the error in the assumed latitude as explained on p. 170.

CURRENT

Having two positions, one by D. R. and the other by observation, it is possible to compute the set and drift of a current which would carry the vessel from the D. R. position to the observed position. This is done by means of the traverse tables. The *set* of the current is the direction in which it moves; the *drift* is the velocity (per hour). Of course this discrepancy in position is not due entirely to actual current, but it is customary to throw all errors (of steering, etc.) into this calculation.

THE DAY'S RUN

The course and distance made good in the 24 hours preceding may now be calculated, starting from the point of departure or from the ship's position at the preceding noon by observation.

Finally the course to be steered for the destination and the distance to be run are worked out by Middle Latitude or Mercator sailing, or by Great-circle sailing.

THE P.M. SIGHT

The P.M. longitude sight may be worked up in the same manner as the A.M. sight, and serves as a check on the position by D. R. Another determination of the compass error may be made at this time, especially if the course was changed at noon or is about to be changed.

FIXES BY SUMNER LINES

If a vessel is steaming at high speed, or if she is near land, or if for any other reason positions are required oftener than once per day, then Sumner's method is the one best adapted to determining the positions. A fix from two stars taken in the early evening or early morning (twilight) gives the best possible position because there is no uncertainty about the run. Or, a sight on a star in the morning combined with the regular A.M. sight on the sun gives a good position.

Undoubtedly St. Hilaire's method is the best one to use for nearly all cases of Sumner's method. Until the student is familiar with this method, however, probably his best plan will be to work up his A.M. sight with an

assumed Lat. and to plot the position line on the chart; then to work up any sight nearer to noon as a $\phi'\phi''$ sight and plot this line on the chart. When the first line is corrected for the run during the interval the two lines cross at the ship's true position at the time of the second observation. In this way the navigator has the benefit of Sumner's method without having to learn any new method of calculation. The noon observation for latitude of course gives a Sumner line running exactly east and west and may be plotted without looking up its azimuth.

THE LOG BOOK

All of the results mentioned above should be carefully entered in the log book. The log should show clearly the following information:

Lat. by obs. at noon.
Long. by obs. at noon.
Lat. by D. R. at noon.
Long. by D. R. at noon.
Course and distance made good.
Current in 24 hours.
Distance run since departure.
Course to steer for destination.
Distance to run to destination.

It should also contain a record of the meteorological observations taken during the day; a record of the amount of fuel consumed and the amount on hand; and of the events of the day, such as objects sighted, vessels met or passed, etc.

In order to illustrate how some of the preceding problems would be applied in the day's work of the navigator we will suppose that a vessel left Boston at 2 P.M. on Oct. 1, 1917 (Eastern Standard Time) and at $3^h\ 05^m\ 00^s$ P.M. was at Boston Light Ship (42° 20'.4 N, 70° 45'.5 W from chart); chronometer time $8^h\ 06^m\ 30^s$. At the time of leaving port the chronometer was found by comparison to be $1^m\ 29^s$ fast of G. M. T. and gaining $0^s.5$ daily. The ship's clock was set to local apparent time from the following computation.

Chro.	$8^h\ 06^m\ 30^s$
C. C.	−1 29
G. M. T.	8 05 01
Long.	4 43 02
L. M. T.	3 21 59
Eq. t.	+10 19
L. A. T.	$3^h\ 32^m\ 18^s$

The clock was therefore $27^m\ 18^s$ slow and was set ahead 27^m, making it 18^s slow.

The course to steer for the first turn in the trans-Atlantic track (Pilot Chart) is found as follows:

Lat. of Turn	43° 00' N	Long. of Turn	50° 00' W
Lat. left	42 20 .4	Long. left	70 45 .5
D. Lat.	39'.6 N	D. Lo.	20° 45'.5 E
Middle Lat.	42° 40'		= 1245'.5
		Dep. =	915'.8 E

from which true course = 87°½

The mean variation is 17° W; deviation, from table, 2° W. The compass course is 106°½ (or S 73°½ E).

At $7^h\ 10^m\ 30^s$ A.M. (ship's time) having run 309 miles the alt. $\underline{\odot}$ is taken, $20°\ 11'$; height of eye, 36 ft.; I. C., $+\ 1'\ 20''$; chro. time, $23^h\ 44^m\ 40^s$. The compass bearing of the sun at $7^h\ 15^m$ is $126°\ 30'$.

Bringing the D. R. position up to this time we find:

True course	Dist.	D. lat. (N)	Dep. (E)	D. Lo.
$87°\frac{1}{2}$	309	$13'.6$	$308'.6$	$418'.6$
				$= 6°\ 58'.6$

Lat. left	$42°\ 20'.4$	Long. left	$70°\ 45'.5$
D. Lat.	$13\ .6$	D. Lo.	$6\ \ 58\ .6$
Lat. in (by D. R.)	$42°\ 34'.0$ N	Long. in (by D. R.)	$63°\ 46'.9$ W

Working out the time sight with this D. R. Lat. (Decl., $-\ 3°\ 27'.0$; Eq. t., $+\ 10^m\ 31^s$) we find the longitude to be $63°\ 45'.6$. The Long. factor is 0.35.

From the observed bearing of the sun the deviation is found as follows:

For Lat. $42°\ 34'$, Decl., $-\ 3°\ 27'$, L. A. T., $7^h\ 43^m\ 10^s$, the true azimuth by table is $105°\ 33'$.

Observed bearing	$126°\ 30'$
Compass error	$20°\ 57'$ W
Variation	19 W
Deviation	$1°\ 57'$ W

The variation is now $19°$, so the compass course is changed at 8 A.M. to $108°\frac{1}{2}$ (or S $71°\frac{1}{2}$ E).

At 11^h A.M. the clock is set to L. A. T. of the meridian 61° 54′ W, where the ship will probably be at noon. At the time of the morning sight the clock was 28^m 10^s slow. The difference between 63° 45′.6 and 61° 54′ turned into time is 7^m 26^s, making the clock slow 35^m 36^s on L. A. T. of meridian 61° 54′ W.

At noon (Oct. 2) the alt. $\underline{\odot}$ is 43° 37′; ht. of eye, 36 ft.; I. C., + 1′ 30″; (Decl., − 3° 31′.3). The resulting Lat. is 42° 40′.9 N.

Carrying the A.M. (D. R.) position up to noon by traverse, we have:

True course	Dist.	D. Lat. (N)	Dep. (E)	D. Lo.
87°½	84	3.6	83.9	113.6
				= 1° 53′.6

Lat. (D. R.) A.M.	42° 34′.0 N	Long (D. R.) A.M.	63° 46′.9 W
D. Lat.	3 .6 N	D. Lo.	1 53 .6 E
Lat. (D. R.) noon	42° 37′.6 N	Long. (D. R.) noon	61° 53′.3 W

This shows that the position at noon by D. R. is 3′.3 too far S. The A.M. longitude should therefore be corrected by an amount equal to $3'.3 \times 0.35 = 1'.16$. Since the position line bears NE and SW an increase in the latitude produces a decrease in the longitude. The longitude is corrected as follows:

Calc. Long.	63° 45′.6
Corr.	−1 .2
A.M. Long.	63° 44′.4
Run to noon	1 53 .6
Long. (by obs.) noon	61° 50′.8

Instead of working up the longitude with the D. R. Lat., 42° 34'.0, we might have waited until noon when we have the correct Lat. 42° 40'.9; this Lat. when corrected for the run gives 42° 37'.3 for the Lat. at time of A.M. sight. Working up the longitude with this Lat. would give 61° 50'.8 W, as already found.

The course and distance made good since leaving point of departure is then worked out.

Lat. of dep.	42° 20'.4	Long. of dep.	70° 45'.5
Lat. in	42 40 .9	Long. in	61 50 .8
D. Lat.	20'.5 N	D. Lo.	8° 54'.7 E
			= 534'.7
		Dep. =	394 .2

Course 87°, Dist. made good, 395', to noon.
Average speed 19.2 knots.

At chronometer time $8^h\ 00^m\ 30^s$ the alt. $\odot$ was 24° 54'; ht. of eye, 36 ft.; I. C., + 1' 10"; run, 76 miles. (Decl., − 3° 35'.1; Eq. t., + $10^m 37^s.6$.) At chro. time $8^h\ 05^m$ the compass bearing of the sun was 278°½; variation 22° W.

Running the position up to P.M. sight we have:

True course	Dist.	D. Lat. (N)	Dep. (E)	D. Lo.
87°½	76	3'.4	75'.9	103'.3
				= 1° 43'.3

Lat. noon	42° 40'.9 N	Long. noon	61° 50'.8
D. Lat.	3 .4	D. Lo.	1 43 .3
Lat. (P.M.)	42° 44'.3 N	Long. (P.M.)	60° 07'.5

Working the time sight with this D. R. Lat. the longitude comes out 60° 09′.6 W.

From the compass bearing of the sun the deviation is found to be 3° W.

At chro. time $11^h\ 01^m\ 20^s$ (Long. 58° 48′ W) the altitude of Polaris was 42° 46′; ht. of eye, 36 ft.; I. C., + 1′ 20″. The latitude as computed from this observation is found to be 42° 48′.4 N.

PROBLEMS

1. Example of Day's Work. The noon position on July 19, 1917, was Lat. 39° 44′ N, Long. 40° 41′ W. The course was 301°, per compass, variation 23° W, deviation 5° W, distance 252 miles up to time of A.M. sight July 20, 1917. The obs. alt. $\underline{\odot}$ was 31° 01′ 20″; watch time, $7^h\ 39^m\ 27^s$ A.M. C − W, + $3^h\ 06^m\ 49^s$; C. C., + 08^s; ht. of eye, 30 ft.; I. C., + 10″. At watch time $7^h\ 44^m\ 00^s$ A.M. the bearing of the sun by standard compass was 117°, heading 301°. The variation by chart was 22° W. The ship then sailed on course 301° by compass, 41 miles, var. 22° W. dev. (as above), to noon. At noon the obs. alt. $\underline{\odot}$ was 70° 37′ 40″; I. C., + 10″; ht. of eye, 30 ft.; chron. $3^h\ 08^m\ 00^s$.

Find the position at noon by D. R., position at noon by observation, dev. of compass from A.M. sight, course and Dist. made good in 24^h, set and drift of current, and course and distance to sail to Lat. 40° 25′ N, Long. 74° 00′ W.

The data required from the N. A. are as follows: At 22^h G. M. T., July 19, the Decl. is + 20° 45′; H. D.,

0'.5; Equa. of time $-$ 6^m $07^s.0$; H. D., $0^s.2$. At 4^h G. M. T. July 20, 1917, the Decl. is $+$ 20° 42'.2; H. D., 0'.5.

Ans. The D. R. position at time of A.M. sight is 39° 57.2 N, Lo. 46° 09'.5 W. Working out the time-sight, the Long. by obs. is 46° 11' 30" W. The azimuth of the sun is N 88° 35' E. The compass error is 28° 25' W, from which the dev. is found to be 6° 25' W. The D. R. position at noon is Lat. 39° 59'.3 N, Long. 47° 02'.9 W. From the obs. at noon we have, Lat. by obs. = 39° 54' 39" N. Bringing the observed Long. up to noon by the run we have Long. at noon by obs. 47° 04'.9 W. The course and distance made good are, course 272°, dist. 294 mi. The current has a set of S 22° W, drift 5.1 mi. The course to steer is 271° 24', dist. to destination, 1244.2 miles.

2. Noon position, Oct. 26, 1917, 35° 01' N; 64° 10' W. Course (per compass), 128°; var., 13° W; dev., 5° E; run to A.M. sight, Oct. 27, 299 miles. At A.M. sight the alt. $\underline{\odot}$ was 28° 21' 30"; I. C., 20", on the arc; ht. of eye, 30 ft.; chro. time, 23^h 21^m 50^s. On Oct. 1 the chronometer was 1^m 20^s slow of G. M. T.; on Sept. 8 it was 1^m 01^s slow. The run from A.M. sight to noon was 61 miles; course (per compass), 129°; var., 14° W; dev., 5° E. Meridian alt. $\underline{\odot}$ was 45° 05' 20" (bearing south); I. C., 20", on the arc; ht. of eye, 30 ft.

Find the Lat. and Long. at noon Oct. 27; the course and Dist. made good since preceding noon; set and drift of current in 24^h; and the course and dist. to steer for Lat. 10° N, Long. 30° W.

The Decl. of the sun at 0^h, Oct. 27, G. M. T., is $-12° 41'.3$; at 2^h, $-12° 43'.0$; at 4^h, $-12° 44'.7$; the H. D. is $0'.9$. The Equa. of time at 0^h is $+16^m 01^s.2$; at 2^h, $+16^m 01^s.7$; at 4^h, $+16^m 02^s.1$; H. D., $0^s.2$.

Ans. Noon position by obs. $\begin{cases}\text{Lat. } 32° 00'.8 \text{ N.} \\ \text{Long. } 57° 57'.6 \text{ W.}\end{cases}$

Course and Dist. made good, 120°, 360 mi.
Current, 259°, 1.1 mi.
Course to steer; True, 130°; comp., 140°.
Dist., 2046.

CHAPTER XIII

MISCELLANEOUS RULES — TIDES — SIGNALS

UNCERTAINTY OF CALCULATED POSITION

It should not be forgotten that it is impossible to obtain the exact position of the ship by observation. Every altitude taken with the sextant is subject to error, due to refraction, errors of adjustment of the instrument, uncertainty in the chronometer correction, etc., and the resulting latitude or longitude is correspondingly in error. The ship's position should not be considered to be exactly at the calculated point, but somewhere within a certain area. A safe procedure is to draw about the computed position a circle whose radius is equal to the estimated error, say 2 miles. The ship may be anywhere within this circle.

A more exact way to define the area containing the true position is to draw two lines parallel to the Sumner line, one on each side, the distance away being equal to the estimated error, say 2′. Where the two Sumner lines cross there will be a parallelogram 4′ wide which contains the true position of the ship.

THROWING AWAY THE SECONDS

There is always a temptation, when working out a position, to keep the angles in even minutes and to neglect the odd seconds because the work is easier, and,

since we frequently find that the position is in error by more than a minute, it would seem to be safe to drop the seconds all the way through the work. This is not, however, a safe procedure; the seconds will accumulate, and furthermore it often happens that an error of a few seconds in one of the numbers will produce an error of whole minutes in the final result. For example, if we throw away $30''$ in the observed altitude, and the same amount in the I. C., the corr. to alt., and the declination, our latitude might be in error by $2'$ owing wholly to the rejection of seconds, to say nothing of the additional error that might come from poor observing. As another instance, suppose that in winter we are obliged to work out a time sight taken when the sun is rather near the meridian. If the altitude is $25°$, the Lat. $40°$ N, and the Decl. $20°$ S, an error due to dropping $30''$ in the altitude and $30''$ in the Decl. may throw the computed longitude out by nearly $3'$. The only safe rule is to keep the odd seconds. Since working to single seconds is too accurate and working to minutes not accurate enough, a good plan is to carry all work to tenths of minutes.

SUN'S DECLINATION FROM AN OLD ALMANAC

To obtain the sun's declination on any day from an Almanac of the *preceding year*. Take out the Decl. for the same date, but for a *time* 6^h *earlier*. The result is generally correct within a small fraction of a minute; i.e., for noon Jan. 3, 1912, take out Decl. for 18^h, Jan. 2, 1911. On a leap year, after March 1, add 1 day to the date before entering the Almanac.

To use an Almanac dated 4 years before the present date: take out the Decl. for the same date but for a time 1^h *later*, i.e., for 5 P.M. May 19, 1920, take out Decl. for 6 P.M. May 19, 1916.

TIDES

When taking soundings or when navigating in shoal water the navigator should be able to ascertain the time of high water and to make allowance for the height of the tide. The time and heights of high and low water are given for every day, and for all the principal ports, in the Tide Tables issued by the Government. Exact directions for using these tables are printed at the foot of each page.

If the Tide Tables are not at hand the time of high tide may be found as follows:

Take from the N. A. the time of upper transit of the moon over the meridian of Greenwich, and also the daily variation. Apply to this time of transit the correction given in Table 11, Bowditch (or Table IV, N. A.); add the correction in west longitude, subtract in east longitude. Add to this result the high-water lunitidal interval of the port. (Appendix IV, Bowditch.) This gives the time of High Water. The "establishment of the port" as given on the charts may be used in place of the lunitidal interval.

Example. Find the time of High Water in the morning of Sept. 22, 1917, at Boston, Long. 71° W. Sept. 22 A.M. will be Sept. 21, Astronomical time.

From the N. A. we find:

Time of Transit of Moon	$3^h\ 35^m$
Variation per hour	54^m

From Table 11, Bowditch (or Table IV, N. A.) the correction is 10^m, to be added, because the longitude is west. The corrected time of transit is $3^h\ 45^m$. From Appendix IV we find that the lunitidal interval is $11^h\ 27^m$, which added to $3^h\ 45^m$ gives $15^h\ 12^m$ astronomical time, or $3^h\ 12^m$ A.M. civil time, Sept. 22.

By working from the moon's lower transit the time of low water may be found in a similar manner.

In allowing for the height of tide it should be remembered that the height changes very slowly at the times of high and low water, but rapidly at half tide. No definite rule can be given for the variation in height because this is different in different places, but the approximate rule is sometimes given that the

rise or fall is one-eighth the total range for the first hour from high or low water, one-quarter of the range at the end of the second hour and one-half at the end of the third hour.

The range for each port is given in Appendix IV, Bowditch.

These general rules take no account of the effect of tidal currents. Information about the currents in particular localities will be found in the Tide Tables.

STORMS — STORM SIGNALS

For a discussion of the theory of revolving storms see Bowditch, p. 212.

To find the direction of the center of a revolving storm:

Face the wind; then if in North latitude the center is from 8 to 10 points to the right. If in South latitude the center is from 8 to 10 points to the left.

To find which "semicircle" the ship is in:

If the wind shifts toward the right the ship is in the right (or dangerous) semicircle (looking along the track of the storm). If the wind shifts toward the left the ship is in the left (or navigable) semicircle.

RULES FOR MANEUVERING A VESSEL IN THE PRESENCE OF CYCLONIC STORMS

[Pilot Chart, Hydrographic Office.]

NORTHERN HEMISPHERE

Right or dangerous semicircle. — Steamers: Bring the wind on the starboard bow, make as much way as possible, and if obliged to heave to, do so head to sea. Sailing vessels: Keep close hauled on the starboard tack, make as much way as possible, and if obliged to heave to, do so on the starboard tack.

Left or navigable semicircle. — Steam and sailing vessels: Bring the wind on the starboard quarter, note the course and hold it. If obliged to heave to, steamers may do so stern to sea; sailing vessels on the port tack.

On the storm track, in front of center. — Steam and sailing vessels: Run for the left semicircle with wind on starboard quarter, and when in that semicircle maneuver as above.

On the storm track, in rear of center. — Avoid it by the best practicable route, having due regard for the storm's recurving to the northward and eastward.

SOUTHERN HEMISPHERE

Left or dangerous semicircle. — Steamers: Bring the wind on the port bow, make as much way as possible, and if obliged to heave to, do so head to sea. Sailing vessels: Keep close hauled on the port tack, make as much way as possible, and if obliged to heave to, do so on the port tack.

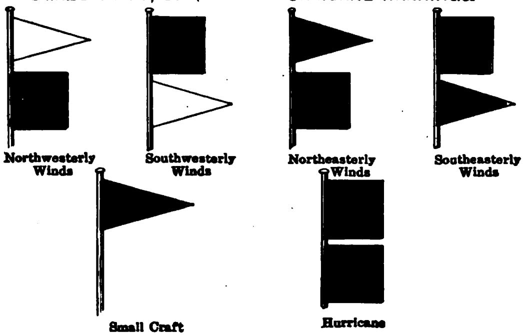
Right or navigable semicircle. — Steam and sailing vessels: Bring the wind on the port quarter, note the course and hold it. If obliged to heave to, steamers may do so stern to sea; sailing vessels on the starboard tack.

On the storm track, in front of center. — Steam and sailing vessels: Run for right semicircle, with wind on port quarter, and when in that semicircle maneuver as above.

On the storm track, in rear of center. — Avoid it by the best practicable route, having due regard for the storm's recurving to the southward and eastward.

The above rules depend, of course, upon having sea room. In case land interferes, a vessel should heave to, as recommended for the semicircle in which she finds herself.

SMALL CRAFT, STORM AND HURRICANE WARNINGS.



Small craft warning. — A red pennant indicates that moderately strong winds are expected.

Storm warning. — A red flag with a black center indicates that a storm of marked violence is expected.

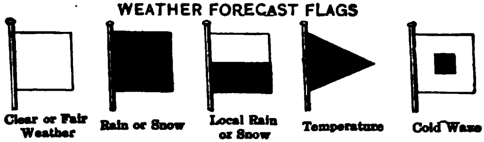
The pennants displayed with the flags indicate the direction of the wind: White, westerly; red, easterly. The pennant above the flag indicates that the wind is expected to blow from the northerly quadrants; below, from the southerly quadrants.

By night a red light indicates easterly winds, and a white light below a red light, westerly winds.

Hurricane warning. — Two red flags with black centers displayed one above the other, indicate the expected approach of a tropical hurricane, or one of those extremely severe and dangerous storms which occasionally move across the Lakes and northern Atlantic coast.

Small craft or hurricane warnings are not displayed at night.

WEATHER FORECAST FLAGS



Number 1, white flag, indicates clear or fair weather. Number 2, blue flag, indicates rain or snow. Number 3, white and blue flag (parallel bars of white and blue), indicates that local rains or showers will occur, and that the rainfall will not be general. Number 4, black triangular flag, always refers to temperature; when placed above numbers 1, 2, or 3 it indicates warmer weather; when placed below numbers 1, 2, or 3 it indicates colder weather; when n t displayed, the indications are that the temperature will remain stationary, or that the change in temperature will be slight. Number 5, white flag, with black square in center, indicates the approach of a *sudden* and *decided* fall in temperature, and is displayed alone.

When displayed on poles the flags should be arranged to read downward; when displayed from horizontal supports a small streamer should be attached to indicate the point from which the flags are to be read.

Signals — Lights — Rules of the Road

WHISTLE SIGNALS

The whistle signals for steam vessels are:

One short blast (one second), meaning, "I am directing my course to starboard."

Two short blasts, meaning, "I am directing my course to port."

Three short blasts, meaning, "My engines are going full speed astern."

Four or more short blasts, meaning, "You are standing into danger."

RULE I. If, when steam vessels are approaching each other, either vessel fails to understand the course or intention of the other, from any cause, the vessel so in doubt shall immediately signify the same by giving several short and rapid blasts, not less than four, of the steam whistle, the DANGER SIGNAL.

RULE II. Steam vessels are forbidden to use what has become technically known among pilots as "CROSS SIGNALS," that is, answering one whistle with two, and answering two whistles with one.

RULE III. The SIGNALS FOR PASSING, by the blowing of the whistle, shall be given and answered by pilots, in compliance with these rules, not only when meeting "head and head," or nearly so, but at all times, when the steam vessels are in sight of each other, when passing or meeting at a distance within half a mile of each other, and whether passing to the starboard or port.

The whistle signals provided in the rules for steam vessels meeting, passing, or overtaking, are never to be used except when steam vessels are in sight of each other, and the course and position of each can be determined in the daytime by a sight of the vessel itself, or by night by seeing its signal lights. In fog, mist, falling snow or heavy rainstorms, when vessels can not so see each other, fog signals only must be given.

The following condensed statements cover some of the more important cases.

When steam vessels are approaching each other head and head, or nearly so, it shall be the duty of each to pass on the port side of the other.

When a steam vessel is nearing a short bend or curve in the channel, which is obscured by high banks, such steam vessel shall give a signal by one long blast of the whistle.

When steam vessels are moved from their docks they shall give one long blast, 4 to 6 seconds, but after clearing the berth so as to be in sight they shall be governed by the steering and sailing rules.

When steam vessels are running in the same direction and the vessel which is astern shall desire to pass on the right of the vessel ahead she shall give one short blast of the whistle. If the vessel ahead answers with one blast she shall then put her helm to port. If she shall desire to pass on the left she shall give two short blasts of the whistle, and if the vessel ahead answers with two blasts she shall put her helm to starboard. If the vessel ahead does not think it safe to pass at that point she shall give 4 or more short blasts of the whistle.

When two steam vessels are approaching each other at right angles or obliquely the steam vessel which has the other on her own starboard side shall keep out of the way of the other vessel.

When a steam vessel and a sailing vessel are approaching, the steam vessel shall keep out of the way of the sailing vessel.

A steam vessel which is directed by the rules to keep out of the way of another vessel shall avoid crossing ahead of the other.

In narrow channels every steam vessel shall keep to that side of the channel which lies on the starboard side of such vessel.

In fog a steam vessel under way shall sound a prolonged blast at intervals of not more than one minute. A steam vessel towing other vessels shall sound one long and two short blasts. A vessel at anchor shall ring the bell rapidly for 5 seconds at intervals of not more than one minute.

SAILING VESSELS

When two sailing vessels are approaching:

(a) A vessel which is running free shall keep out of the way of a vessel which is close hauled.

(b) A vessel close hauled on the port tack shall keep out of the way of a vessel close hauled on the starboard tack.

(c) When both are running free, with the wind on different sides, the vessel which has the wind on the port side shall keep out of the way of the other.

(d) When both are running free, with the wind on the same side, the vessel which is to the windward shall keep out of the way of the vessel which is to the leeward.

(e) A vessel which has the wind aft shall keep out of the way of the other vessel.

LIGHTS

A steam vessel under way is obliged to carry a green light on the starboard side and a red light on the port side, visible everywhere from right ahead to two points abaft the beam. She also carries a white light at the masthead, not less than 20 feet above the hull, and visible at a distance of at least 5 miles. She may carry an additional white light, the two to be in line with the keel, their difference in height to be at least 15 feet, and the lower light to be forward of the upper one.

A steam vessel towing another vessel carries also two bright white lights, in a vertical line, and not less than 6 feet apart.

A vessel which, owing to accident, is not under command must carry two red lights at the height of, and in place of, her white masthead light. These lights must be in a vertical line and at least 6 feet apart.

Pilot vessels, when on duty, do not show the lights required for other vessels, but carry a white light at the masthead and show a flare-up light every 15 minutes. A steam pilot vessel, on duty, carries also a red light 8 feet below her masthead light.

A sailing vessel under way and a vessel being towed shall carry the red and green lights required for steamers, but shall not carry the white lights.

A vessel at anchor does not carry the red and green lights but shows one or two white lights according to her length.

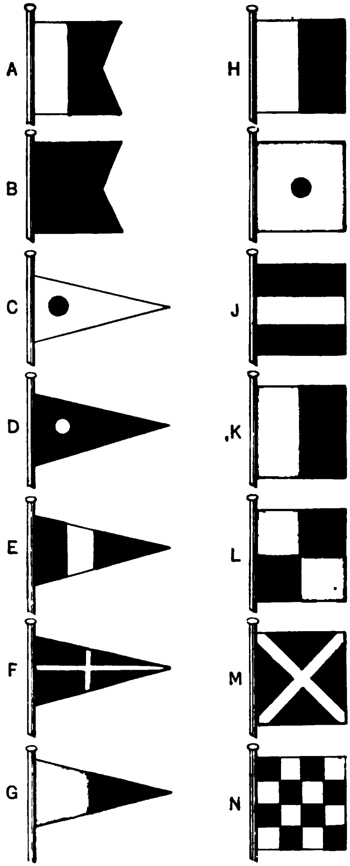
A complete statement of the laws and rules concerning lights, signals, etc., is given in "Pilot Rules, etc.," issued by the Department of Commerce, Steamboat Inspection Service, and in Circular No. 230, Dept. of Commerce, Bureau of Navigation.

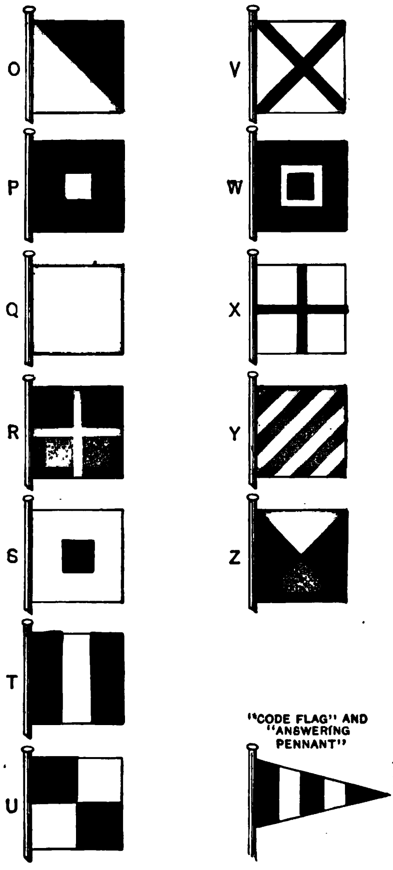
INTERNATIONAL SIGNAL CODE

The International Code of Signals consists of 26 flags, one for each letter of the alphabet, and the code flag or answering pennant (pp. 200-1). Two of these (A, B) are burgees, five (C to G) are pennants and the rest are square flags. The Code Book is published by the Navy Department and contains full instructions for making and answering all signals. The International Code is printed in all languages, so that vessels may communicate without either one understanding the written language of the other.

The flags each have a certain meaning when hoisted singly or with the code pennant. Urgent signals are made with two flags. Three flag signals are usually compass or general vocabulary signals. Three-flag signals with the code pennant at the top are for latitude and longitude. Four-flag hoists are geographical or alphabetical signals.

To open communication by the Code, show the ensign with the code pennant under it. This should be answered by hoisting the answering pennant (code pennant


A
B
C
D
E
F
G
H
I
J
K
L
M
N



When used as the Code Flag it is to be hoisted under the Ensign.
When used as the Answering Pennant it is to be hoisted at the mast head or where best seen.

by itself). When the signal itself is hoisted the code flag is hauled down. Each hoist should be answered by the answering pennant. When a ship has finished signaling she hauls down her ensign.

Communication may be commenced. and any messages following, or found under the heading "Danger or Distress" in the International Code Signal Book, may be exchanged, strictly following the International Commercial Code and the instructions given below.

The above signal, asking to open communication, should be shown in every case of distress by the shore station, for it may be that the vessel has the International Code, but, until seeing this signal, will not know that she can use it.

SIGNALS ADOPTED FROM AND TO BE FOUND IN INTERNATIONAL COMMERCIAL CODE SIGNAL BOOK

N C	In distress; want immediate assistance	F R	Bar is impassable
D C	We are coming to your assistance.	I E D	Cast off
E Y	Do not attempt to land in your own boats.	R I F	Make fast to ——
B I	Damaged rudder; cannot steer.	W F Q	Slack away
B J	Engines broken down; I am disabled.	K T	Shift your berth. Your berth is not safe.
J D	You are standing into danger	K P	Hold on until high water.
F Z	Heavy weather coming; look sharp.	K H	Remain by the ship.
A B	Abandon the vessel as fast as possible.	Y F	Want assistance; mutiny.
K D	Landing is impossible.	Y L	Want immediate medical assistance.
K F	Look out for rocket line (*or*, line).	Y G	Want a boat immediately (*if more than one, number to follow*).

K A	Endeavor to send a line by boat (cask, kite, raft, etc.).	Y P	Want a tug (*if more than one, number to follow*).
C X	No assistance can be rendered; do the best you can for yourselves.	A G	I must abandon the vessel.
K G	Lookout will be kept on the beach all night.	P T	Want a pilot.
K E	Lights, or fires will be kept at the best place for coming on shore.	V G	What is name of ship or signal station in sight?
K C	Keep a light burning.	D U	Repeat ship's name; your flags were not made out.
A D	Do not abandon the vessel until the tide has ebbed.	W C X	Signal not understood; though the flags are distinguished.
N M	I am on fire.	N C X	I cannot make out the flags (*or,* signals).
N O	I am sinking (*or,* on fire); send all available boats to save passengers and crew.	C	Assent — yes.
		D	Negative — no.

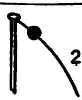
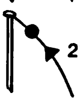
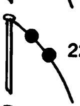
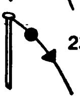
SPECIAL DISTANT SIGNALS

The following distant signals may be used when, on account of distance, the code flags cannot be distinguished.

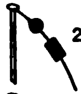
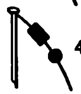
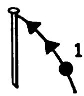
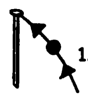
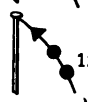
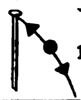
SPECIAL DISTANT SIGNALS

Made by a single hoist followed by the STOP signal. Arranged numerically for reading off a signal.

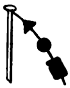
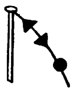
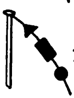
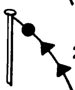
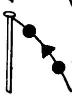
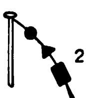
These Signals may be made by the Semaphore, by Cones, Balls, and Drums, or by Square Flags, Balls, Pennants, and Whefts.

SIGNAL	MEANING
 2	"Preparative," "Answering," *or*, "Stop," after each complete signal.
 12	Aground; want immediate assistance.
 21	Fire, *or* Leak; want immediate assistance.
 22	Annul the whole signal.
 23	You are running into danger, *or* Your course is dangerous.

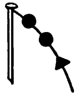
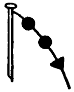
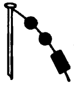
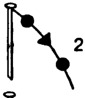
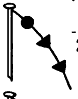
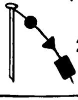
Special distant signals, arranged numerically

SIGNAL	MEANING
 24	Want water immediately.
 32	Short of provisions; starving.
 42	Annul the last hoist; I will repeat it.
 112	I am on fire.
 121	I am aground.
 122	Yes, *or*, affirmative.
 123	No, *or*, Negative

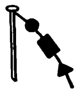
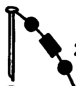
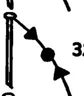
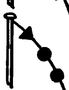
Special distant signals, arranged numerically

SIGNAL	MEANING
 124	Send lifeboat.
 132	Do not abandon the vessel.
 142	Do not abandon the vessel until the tide has ebbed.
 211	Assistance is coming.
 212	Landing is impossible.
 213	Bar, *or*, Entrance is dangerous.
 214	Ship disabled; will you assist me into port?

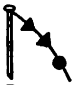
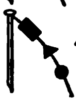
Special distant signals, arranged numerically

Signal		Meaning
	221	Want a pilot.
	223	Want a tug; can I obtain one?
	224	Asks the name of ship (*or*, signal station) in sight, *or*, Show your distinguishing signal.
	231	Show your ensign.
	232	Have you any dispatches (message, orders, *or*, telegrams) for me?
	233	Stop, Bring-to, *or*, Come nearer; I have something important to communicate.
	234	Repeat signal, or hoist it in a more conspicuous position.

Special distant signals, arranged numerically

SIGNAL	MEANING
 241	Can not distinguish your flags; come nearer, or make Distant Signals.
 242	Weigh, Cut, *or*, Slip; wait for nothing; get an offing.
 243	Cyclone, Hurricane, *or*, Typhoon expected.
 312	Is war declared? *or*, Has war commenced?
 321	War is declared, *or*, War has commenced.
 322	Beware of torpedoes; channel is mined.
 323	Beware of torpedo boats.

Special distant signals, arranged numerically

SIGNAL	MEANING
 324	Enemy is in sight.
 332	Enemy is closing with you, *or*, You are closing with the enemy.
 342	Keep a good look-out, as it is reported that enemy's men-of-war are going about disguised as merchantmen.
 412	Proceed on your voyage.

DISTRESS SIGNALS

(SEE ARTICLE 31 OF INTERNATIONAL RULES.)

When a vessel is in distress and requires assistance from other vessels or from the shore the following shall be the signals to be used or displayed by her, either together or separately, namely:

In the daytime —

(1) A gun or other explosive signal fired at intervals of about a minute.

(2) The International Code signal of distress indicated by NC.

(3) The distant signal, consisting of a square flag,

having either above or below it a ball or anything resembling a ball.

(4) A continuous sounding with any fog-signal apparatus.

At night —

(1) A gun or other explosive signal fired at intervals of about a minute.

(2) Flames on the vessel (as from a burning tar barrel, oil barrel, and so forth).

(3) Rockets or shells throwing stars of any color or description, fired one at a time, at short intervals.

(4) A continuous sounding with any fog-signal apparatus.

FORMULAS

No formulas have been introduced into the text because it was assumed that those using the book may not be accustomed to algebraic notation. Those who prefer the formulas will find in the following table all of the important formulas which have been used in the book.

Plane Sailing

Known	Find	Formulas
Course (C) and Distance	D. Lat. and Dep.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C
D. Lat. and Dep.	Course and Dist.	log tan C = log Dep. − log D. Lat. log Dist. = log Dep. − log sin C

Parallel Sailing

Dep. and Lat.	D. Lo.	log D. Lo. = log Dep. + log sec Lat.
Lat and D. Lo.	Dep.	log Dep. = log D. Lo. + log cos Lat.

Middle Latitude Sailing

Known	Find	Formulas
Both Lats. and Longs.	Dep., Course and Dist.	log Dep. = log D. Lo. + log cos mid. Lat. log tan C = log Dep. − log D. Lat. log Dist. = Dep. + log csc C
Lat., Dep. and mid. Lat.	Course, Dist. and D. Lo.	log tan C = log Dep. − log D. Lat. log Dist. = log Dep. + log csc C log D. Lo. = log Dep. + log sec mid. Lat.
Lat. left, Course and Dist.	D. Lat., Dep. and D. Lo.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C log D. Lo. = log Dep.+log sec. mid. Lat.

Mercator Sailing

Both Lats. and Longs.	Course, Dist. and Dep.	log tan C = log D. Lo. − log m. log Dist. = log D. Lat. + log sec C log Dep. = log Dist. + log sin C.
Lat. and Long. left, Course and Dist.	D. Lat., D. Lo.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C log D. Lo. = log m + log tan C

Great Circle Sailing

$$\tan \phi = \cos \text{D. Lo.}_{AB} \cot \text{Lat.}_B$$
$$\cot C_A = \cot \text{D. Lo.}_{AB} \cos (\text{Lat.}_A + \phi) \csc \phi$$
$$\sin \text{Dist}_{AB} = \sin \text{D. Lo.}_{AB} \cos \text{Lat.}_A \csc C_A$$

(C_A = initial course in sailing from A to B.)

Latitude

MERIDIAN ALTITUDE

$$\text{Lat.} = 90° - \text{Alt.} + \text{Decl.}$$

ϕ' ϕ'' SIGHT

$$\log \tan \phi'' = \log \tan \text{Decl.} + \log \sec t \text{ (hour angle)}.$$
$$\log \cos \phi' = \log \sin \text{alt.} + \log \sin \phi'' + \log \csc \text{Decl.}$$
$$\text{Lat} = \phi' + \phi''.$$

Longitude

TIME SIGHT

$$s = \tfrac{1}{2} (\text{alt.} + \text{Lat.} + \text{p. dist.})$$
$$\log \sin \tfrac{1}{2} t = \tfrac{1}{2} [\log \sec \text{Lat.} + \log \csc \text{p. dist.} + \log \cos s + \log \sin (s - \text{alt.})]$$

or

$$\log \text{hav.} = [\log \sec. \text{Lat} + \log \csc \text{p. dist.} + \log \cos s + \log \sin (s - \text{alt.})]$$

Azimuth

ALTITUDE–AZIMUTH

$$\log \cos \tfrac{1}{2} \text{Az.} = \tfrac{1}{2} [\log \cos s + \log \cos (s - \text{p. dist.}) + \log \sec \text{Lat.} + \log \sec \text{alt.}]$$

TIME AND ALTITUDE AZIMUTH

$$\log \sin \text{Az.} = \log \sin t + \log \cos \text{Decl.} + \log \sec \text{alt.}$$

Amplitude

$$\log \sin \text{Ampl.} = \log \sec \text{Lat.} + \log \sin \text{Decl.}$$

Altitude

$$\log \text{hav.}\, \theta = \log \cos \text{Lat.} + \log \cos \text{Decl.} + \log \text{hav.}\, t$$

$$\text{nat. hav.}\, Z \text{ (zenith dist.)} = \text{nat. hav.}\, \theta + \text{nat. hav. (Lat} \sim \text{Decl.)}$$

$$\text{Alt.} = 90^\circ - Z.$$

APR 30 1918